THE RELATION OF LEAF STRUCTURE TO PHYSICAL FACTORS

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WITH NINE PLATES

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I. Introduction

The leaf, as the seat of important physiological functions of the plant, and because of its modification by external factors, has long been a fruitful subject for investigation. As a rule, however, investigators have confined themselves solely to the histology and morphology of the leaf, independent of its relations to physical factors. Where the latter have been considered at all, it has been in a more or less general way, or undue importance has been assigned to one or another of the physical factors, and others have been ignored entirely. In no case have they been carefully measured. The aim of the present paper has been to study the histology of the leaves of a comprehensive number of species, and to take careful account of the physical factors which affect leaf structure.

Three objects have been kept clearly in mind: (1) To correlate in a definite way the histology of leaves with the measured physical factors of their habitat; (2) to determine the kind and amount of modification taking place in the leaves of the same species in different habitats; (3) to throw light upon the plasticity of different species and genera.

This investigation was suggested by Doctor Frederic E. Clements, under whose direction it has been carried on. Grateful acknowledgment is here made for helpful suggestions, and for the facilities offered by the Department of Botany at the University of Nebraska, and at the Alpine Laboratory, Minnehaha, Colorado.

II. Historical

Areschoug (78) studied the histology of about fifty plants from the dicotyledons and monocotyledons, and some ferns, and concluded that "the various anatomical types of the dicotyledons are particular forms of one and the same fundamental type which changes in unlike conditions of life."

Jönsson (80) investigated the histology of only a particular family, the Proteaceae.

Haberlandt (81) investigated the leaf histology of a large number of genera and species. He studied them especially with reference to the assimilative cells,and attempted to make clear the relation in which the structure and arrangement of these cells stand to the process of assimilation, and to prove by means of this relation that the assimilative cells are physiologically uniform in spite of the great variety of single constructions. He concluded from his investigations that in leaves of similar structure the specific assimilative energy is approximately proportional to the entire mass of chloroplasts in the leaf units concerned. He also noticed a peculiar form of palisade cell which he called "arm-palisade," and explained the form as due to infoldings of the cell wall for the purpose of increasing the assimilative surface, since chloroplasts were noted in great abundance next to the cell wall. He furthermore classified leaves into types according to the structure of the mesophyll with respect to the physiological principle of the most direct transport of food materials. This principle was considered of more importance than that of the direction of light, in determining the position of palisade cells. The latter he concluded to be perpendicular to the surface of the leaf as a rule, and not parallel to the rays of light. He has explained intercellular spaces as serving, besides the purpose

of aeration, that of keeping food material on the shortest possible route to the bundles.

Vesque & Viet (81) carried on a year's experimentation with plants in the laboratory and out of doors, with particular reference to the effects of humidity and light. They grew plants under bell-jars in different combinations of the two factors, and concluded that humidity has the same effect as darkness on plants, perhaps by decreasing the transpiration stream.

Pick (82) studied the histology of a number of sun and shade leaves and the stems of plants poor in foliage. He concluded that in all cases of sun and shade leaves with the same extent of surface, the former are thicker than the latter, and furthermore, that growth in all directions is decreased by weaker light, but that the air-spaces of shade leaves are larger in most cases. He inclined to the opinion that the elongated form of the typical palisade cell is ancestral, and that it is either further developed on exposure to the sun, or hindered by the shade. He has concluded this from the fact that plants with a typical development of palisade cells show already a sharply defined elongation of the hypodermal cell-layer in the younger leaves of the bud-layer. Moreover he found that there is no significant difference in the young leaves of sun and shade forms of the same species. On the other hand there are also leaves which do not develop the elongated cells until maturity. In the larger number of plants growing on sunny spots, however, the palisade in the upper part of the leaf is ancestral, but for its typical development the influence of strong light intensities is necessary. Deviations from this rule are to be found in the vertically placed leaves of some plants.

Stahl (83) drew the following conclusions from his investigations concerning the influence of light on the finer structure of leaves. Many plants are capable to a high degree of adapting the structure of their leaves to various degrees of light. Sun-leaves are, as a rule, smaller, tougher and thicker than shade-leaves. In sun-leaves the palisade reaches a high degree of development, while in shade-leaves it is reduced and even lost altogether, or takes the form of "funnel-cells." Shade leaves possess loose sponge with unusually large air-spaces which are considerably reduced in sun leaves. The elongated cell form in which the chloroplasts take up the "profile" position is the one best adapted to strong intensities of light, whereas the flat sponge cell is best fitted to weak light. Opposed to "plastic" forms are stable ones which show the same leaf structure under all conditions of light; this is especially true of

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the greater number of monocotyledons. It seems probable that the impulse to the various development of leaves comes from the venation of young leaves. If this stretches more decidedly in the shade than in the sun, the leaf becomes larger and thinner, and its cells drawn more to the surface, than in sun-leaves, where the cells, because of the lesser pull of the veins, stretch out more in the vertical direction.

Krüger (83) investigated twenty-three species and eighteen genera, noting the histological relations which stand in evident connection with the conditions of life. He ascribed their manifold structure to adaptation and heredity, but considered the influence of the former alone, attempting to show, in a more or less general way, how the structure of leaves, buds and stems corresponds to the demands of the habitat. For instance, a certain group of orchids becomes succulent in order to protect against transpiration, and to store up necessary water. Another type produces water-storage cells, and a thick cuticle to reduce transpiration, etc.

Vesque (83) studied the histology of the leaves of the Caryophyllaceae with regard to its bearing on their systematic arrangement.

Johow (84) made a large number of observations in the Lesser Antilles on the relations of leaves to light. He did but little with histology, but noted mainly variations in position and in movement for protection against harmful illumination and excessive transpiration, as well as protective modifications against too intense illumination.

Heinricher (84) made an extensive study of the "isolateral" leaf structure of a large number of plants from different parts of the world. His conclusions are as follows: Isolateral leaf structure is connected with the vertical position of leaves, and is due to the effect of the sunny and, as a rule, dry situations of the species possessing it. Both factors, light and dryness, usually occur united, but the latter does not seem necessary for isolateral structure; it is secondary to strong illumination. Isolateral structure of leaves is found more or less plainly in damp situations. Two species of *Boltonia* possess it, the most hydrophytic one, however, only incompletely. On the other hand, many swamp and water plants with vertical leaves do not have isolateral structure, but do possess a layer of palisade on the under side. High light intensities are responsible for isolateral structure, which has usually arisen from the transformation of the sponge tissue of dorsiventral leaves into

palisade tissue, for the reason that isolateral leaves become more or less dorsiventral when grown in the shade. Isolateral structure, then, is ancestral in illuminated leaves and dorsiventral structure is atavistic in shaded leaves. The stronger the light to which a plant is exposed the more vigorously is the assimilative system developed, and since for dicotyledons the typical assimilative cells are the palisade cells, the entire mesophyll is often made up of palisade cells. Light does not directly affect the form of the cells. It is the factor which leads to greater assimilative activity, and this is best carried out in the elongated form of the palisade cell. All progress in the structure of the assimilative apparatus as well as its quantitative formation is caused by light. Haberlandt's conclusion that the position of the assimilative cells is dependent upon the transport of food and not, as Pick thinks, upon light, is confirmed. The position of the palisade cells is, as a rule, perpendicular to the surface, whereas the leaf occupies all positions with reference to the direction of the light. The displacement of the palisade from the position perpendicular to the surface, is due to the growth of the other tissue elements. The assimilative cells bend towards the bundles. This bending is not noticeable where a sponge tissue is differentiated consisting of many armed cells which take up the function of transport. Exceptions occur where there is no curving of the cells, and where the cells of the bundle sheath have their long axes parallel to the other cells, and perhaps even no connection at all between the cells. This question is left for further investigation with the suggestion of the possible development of the epidermis into a means of transport.

Costantin (85) studied the morphology and histology of the leaves of a number of common aquatic plants. He noted the acquisition or loss of certain characters as the leaves were submerged or aerial, and also such adaptations as the presence or absence of stomata and hairs, and the amount of palisade tissue and air-passages. He also gave a discussion of plant distribution and adaptation to environment in general.

Schenck (86) treated of aquatic plants in a thorough manner, giving a detailed description and the life-history of a number of species as well as their adaptations to the habitat, and the changes which have taken place in the land forms of aquatic species.

Möbius (87) made a comparative study of the structure of orchids, and, while admitting that climate and situation affect leaf structure, referred to it only in single instances. He covered 193

species and 95 genera, giving histological descriptions and their bearing on the systematic arrangement of the orchids. He was especially interested in the influence of heredity, *i. e.*, " the relations between the similarity and dissimilarity of leaves in their more detailed structure to the greater or less relationship in which the species considered stand to one another." He nevertheless admitted that species systematically close together will be unlike in histological structure if they occupy different habitats.

Dufour (87) experimented with plants to find out the effects of light, by growing different individuals of the same species in full sunlight and in shade, keeping all other factors the same. His results were uniformly in favor of greater development of the sun plant in stem, leaves and roots. The leaves of the sun-plant compared with those of the shade-plant were larger, thicker, with thicker cuticle; palisade tissue was more highly developed as well as the conductive and supportive tissues, and chloroplasts, starch and crystals occurred in greater abundance. He ascribed the fact that most investigators have described shade-leaves as usually larger than sun-leaves to be due to the influence of water-content. To prove this he grew plants in very wet and in very dry soil, the other factors remaining the same, and found that the leaves of the former were larger than those of the latter. He explained the occurrence in nature of larger leaves on shade-plants as being due to the fact that as a rule a sunny place is dry and a shady one moist. The preponderance of leaf surface then, would be with the one or the other according to the resultant of the two inverse forces in either spot.

Loebel (89) discussed the structure of the leaves of a number of plants, and their physiological importance, agreeing that the conditions of life exercise a certain influence upon the inner organization of leaves.

Bonnier (90) established stations at different altitudes in the Alps and on the plains in which he planted different parts or seeds of the same plant, taking care that the soil from the higher regions was taken to the plains so that the different plants grew in the same soil. He also chose species which were not peculiar to either plains or high altitudes, but rather those growing at an intermediate altitude, that there might be no question of abnormal development. Out of 203 roots planted 123 survived, and of these 119 remained in the lower stations in such fashion that a comparison could be established for almost all the species chosen. The plants were

grown for six years and compared from time to time as to external appearance and parts, color and dimension of leaves and flowers, development of subterranean parts, etc. It was proved that a plains plant when transplanted to a higher altitude acquires a certain number of characteristic modifications, of which some increase indefinitely with altitude, and others (chlorenchyma, color of flowers) reach their optimum within the limits of the altitude which the species can support. The modifications of the leaves of the alpine plants compared with those of the plains were found to be as follows: the assimilative tissue is better placed for chlorophyll functions; palisade tissue is better developed, either by means of longer closer cells or by increase in number of rows; chloroplasts are more abundant and more deeply colored; secretive canals, where present, are either relatively or absolutely larger; epidermal cells are usually smaller and the number of stomata often greater for unit of surface, especially on the upper surface. Chlorophyll assimilation and chlorovaporization are greater per unit of surface. The causes of the modifications obtained are ascribed to intense illumination, dryer air, and lower temperatures. The first two act in the same way by increasing assimilation and evaporation to produce greater thickness of leaf, greater development of palisade tissue, more chlorophyll in each cell, thicker cuticle and greater number of stomata per unit of surface. To temperature in combination with light and dryness may be attributed all protective tissues.

Wiesner (91) carried on a number of experiments with plants placed in saturated air and in darkness, but noted external changes merely.

Wagner (92) has drawn the following conclusions from a study of alpine plants:

1. The leaves of alpine plants show in every respect an unmistakable adaptation to increased assimilative activity. This is expressed by an increase in the size and number of palisade cells, usually looser structure of the mesophyll, and the widespread occurrence of numerous stomata on the upper surface of the leaves.

2. The grounds for the above development of the assimilative tissue are to be found in:

(*a*) Increased light intensities which arise because of the thinness and dryness of the air.

(*b*) Decrease of absolute carbonic acid content of the air with altitude.

(*c*) Shortened vegetation period.

3. The adaptation to these factors is the greater the more plastic a species is.

4. The leaves of alpine plants do not show such thorough protective devices as such great transpiration is accustomed to call forth. The reason for this lies in the greater relative humidity of the air, and greater soil-water.

5. Since, when exposed to decreased transpiration the alpine plants do not show a reduction but an increase of palisade tissue, it follows that not transpiration but assimilation is more effective as regards the structure of the mesophyll, in such a way that the number and size of the palisade cells are regulated by conditions of assimilation, whereas intercellular spaces are also dependent upon transpiration.

Lazniewski (96) studied the structure of a number of alpine plants both morphologically and histologically. He classified the plants considered according to morphology, and gave a general discussion of humidities in the alpine regions, noting as of especial importance quick changes and great extremes of both humidities and temperatures. He concluded that one cannot speak of a common alpine leaf type or histological leaf structure, since even among the saxifrages vast differences in the structure of the leaf occur, and wet and dry situations are found close together with the characteristic flora. He ascribed the displacement of the palisade cells from a position perpendicular to the leaf surface, to the influence of light.

Kearney (01) made an ecological study of the distribution of plant species of the Dismal Swamp region. He discussed the most striking adaptations to the habitat as expressed in the histology of the leaf as well as in the morphology of the most abundant or otherwise interesting species.

Hansgirg (00–03) classified an immense number of leaves into types with respect to external form, and adaptations to climatic conditions.

Hesselmann (04), in a paper which comes to hand as these pages go to press, has taken up the problem of studying in nature the life processes of plants, and has attempted to gain a conception of the connection between external factors and plant activities. The investigation, which covers several summers, is thorough and scientific. During this period exact records of light, temperature and humidity were made for several stations in the thickets and sunny

meadows of an open woodland formation in Skabholm. The physical and chemical nature of the soil in the various locations was carefully determined but no measurements of the amount of soil-water seem to have been made. Of particular interest, in view of the methods of the present paper, are the exact measurements of light and their direct connection with assimilation, transpiration and leaf structure. The conclusions in this respect are the following: plants in the leafless thickets of the springtime assimilate as vigorously as those in the sunny meadow; reduced light decreases assimilation even to the point of the complete absence of starch formation; plants which mature in continually decreasing but not very weak light, have a less completely developed assimilative tissue than those plants which obtain a great deal of light in the spring but are deeply shaded during the summer; shade-plants transpire less than sun-plants, and of the latter those with well developed palisade transpire more than those with less differentiation in the leaf structure.

III. Physical Factors

The physical factors of a habitat are either climatic or edaphic. The former are those of the atmosphere, *e. g.*, light, temperature and humidity, while the latter are connected with the soil, *viz.*, water, chemical and physical composition, and temperature. Of climatic factors light is by far the most important in its relation to the plant. Some of the light rays are reflected from the surface of the leaf and thus rendered ineffective. The waxy coating of some leaves serves the purpose of increasing the amount of reflected light and so preventing over-illumination. Other of the light rays are transmitted, and it is not known what effect they may have in transmission. Effective light rays are those which are absorbed either directly from the air or upon being reflected from the surface of the soil. The latter, in connection with the heat reflected, especially from light-colored soils, is a considerable factor in leaf structure. Absorbed light acts upon the leaf through the assimilative function. High light values, by increasing assimilation, cause an increase in the assimilative parts, such as chloroplasts and palisade cells, whereas low light values have the opposite effect. Humidity affects leaf structure through increase or decrease of evaporation, while temperature acts through increase or decrease of humidity.

Of edaphic factors, the available water-content of the soil is by

far the most important. It is coming to be generally admitted that the chemical and physical properties of the soil are of importance chiefly in so far as they affect the amount of available water, the former through varying amounts of salts and the latter through the ease with which the particles give up water. In this connection it is important to note that gravel will yield all but 0.5 per cent. of its water, while clay retains 8 per cent. Consequently the water in the soil at any given spot must be considered with reference to the available and not the absolute amount.

The methods for measuring physical factors as laid down in Clements' Research Methods in Ecology were those applied in carrying on the present investigations. On account of the difficulty of covering the large area represented the records are for some regions more or less fragmentary and unsatisfactory. It is hoped, however, that these may be made good by future investigations, and the present results, though incomplete, are to be looked upon as a step at least in the right direction. The records which follow were obtained during the summers of 1903 and 1904.

LIGHT.—Light readings to the number of 110 were made during the two summers by means of the simple photometer. It was found that full sunlight is equally strong throughout the regions, and not more intense for high altitudes, as is generally supposed. The light values in the following table are the noon readings of the various situations expressed in terms of the meridional sunlight of September 12, 1904, at the subalpine station.

WATER-CONTENT OF THE SOIL.—During the two summers 180 records were made throughout the region. The average of those taken in a particular soil or locality is given in the table under "normal water-content." The saturation point of different soils was also obtained, as well as the available water. The latter was determined by measuring the percentage of water left in a soil containing plants at the wilting point. The percentages are based on the moist soil and are, in consequence, a little lower than they would be if figured with reference to the dry weight.

HUMIDITY.—Continuous records of humidity were made in the foot-hills and in the spruce forest and gravel slide of the subapline region by means of automatic psychrographs, during eight weeks of 1904. Readings were made twice daily for the brook bank and half gravel formations of the subalpine region in 1904, and single readings were taken frequently throughout the two summers at a

number of situations and altitudes. The figures in the table indicate the average extremes for the season.

TEMPERATURE.—Continuous automatic records of temperature were made during fifteen weeks of 1903 for the foothills (2000 meters), the subalpine region (2600 m.), and the alpine region (3800 m.). Similar records were made during eight weeks of 1904 in the foothills, and in the spruce forest and gravel slide formations of the subalpine region. Readings for the brook bank and half gravel formations of the subalpine region were made twice daily during 1904. Frequent single readings of soil, air and surface of ground were made during the two summers throughout the three regions. The air temperatures in the table are the average of the daily extremes for the growing season. The ground and soil temperatures are the average of the single readings. All temperature readings are expressed in Fahrenheit degrees.

TABLE OF PHYSICAL FACTORS

	Light	Water-Content			Humidity	Temperature		
		Saturation Point	Normal	Available		Air	Surface of Ground	Soil
Foothills								
Gravel	1	15%	3–6%	2.5–5.5%	28–77%	57°–89°	96°	72°
Half gravel	1	20	6–9	4.5–7.5	28–77	57 –89		
Clay mesa	1	32	10–12	2–4	28–77	57 –89		
Thickets	0.01	varies with soil			38–80	53 –85		
Subalpine								
Gravel	1.–0.1	15	3–6	2.5–5.5	30–65	55 –76	100	68
Half gravel	1.–0.1	20	6–9	4.5–7.5	30–65	51 –76	80	58
Aspens	0.8		15–20	9–14	30–65	50 –75		
Spruce forests	0.03	45	18–22	12–16	40–70	48 –72	62	51
Thickets	0.0125	varies with soil			40–70	48 –72		
Shady brook banks	0.01–0.03	51	35–40	25–30	60–85	47 –69	55	50
Sunny brook banks	1	51	25–35	15–25	50–70	50 –75		
Alpine								
Gravel	1	15	3–6	2.5–5.5	30–50	40 –65	100	
Half gravel	1	20	6–9	4.5–7.5	30–50	40 –65		
Meadows	1	45	20–25	12–17	30–50	40 –65	61	49
Rock clefts	0.05	45	20–25	12–17	40–60	30 –55		
Spruce forests	0.03	varies with soil						
Lakes—water	?	100	100	100	100	40 –65		
" —surface	1	70	70	58	80–90	40 –65		
" —shore	1	70	70	58	50–70	40 –65		

IV. TYPIFICATION OF ENDEMIC SPECIES

The plants studied in relation to their leaf structure and habitat comprise about three hundred species collected in the Colorado foothills and mountains of the Pike's Peak region of the Rocky Moun-

tains. As far as possible, plants bearing mature leaves were gathered at the period of maximum flower or the formation of fruit. Where present, both stem and rosette leaves were preserved for purposes of comparison, but in the following study and classification, stem leaves only are considered. The endemic species are grouped into types according to the comparative histology of their leaves, whereas polydemic species are considered separately with reference to the changes in the leaves of the different habitat forms of each species. In both cases the type species is carefully described according to a certain formula. Among the endemic species this type is followed by a list of all species resembling the type. The individual variations of these are also noted, though in every case their resemblance to the type is greater than their variations from it. Descriptions have been made from the most typical part of the section and in a place where the bundle is cut true. The measurements are usually the average of varying cells, though occasionally extremes are noted. Terms have been used according to the following definitions:

Plants

- endemic—occupying one habitat.
- polydemic—occupying two or more habitats.

Leaves

- xerophyll—the leaf of a xerophyte.
- mesophyll—the leaf of a mesophyte.
- hydrophyll—the leaf of a hydrophyte.
- isophotic (ἴσος, equal, φῶς, φωτός, τό light)—with similar cells throughout or at both surfaces.
- staurophyll (σταυρός, ὁ, an upright pale or stake, φύλλον, τό, leaf)—an isophotic leaf composed of prolate cells.
- spongophyll (σπόγγος, ὁ, sponge, etc.)—an isophotic leaf composed of sponge cells.
- diplophyll (διπλόος, two-fold, etc.)—an isophotic leaf with prolate cells next to either epidermis, and central sponge tissue.
- diphotic (δι- twice, etc.)—differentiated into palisade and sponge tissue at the respective surfaces.

Cells

- prolate—oblong cells in a vertical position.
- oblate—oblong cells in a horizontal position.
- prolobate—with vertical lobes ("armpalisade" of Haberlandt).
- oblobate—with horizontal lobes.

funnel (Haberlandt)—broad at one end and tapering at the other.
Tissues
chlorenchym—the green tissue of the leaf, *i. e.* mesophyll.
compact—with infrequent intercellular spaces.
close—with few small intercellular spaces (smaller than the cells).
loose—with frequent small intercellular spaces.
lacunose—with frequent large intercellular spaces (as large as or larger than the cells).

HYDROPHYTIC TYPES

Alpine lakes: light—; available water 100%; humidity 100%; temperature 40°–65°.

ISOETES LACUSTRIS PAUPERCULA: spongophyll 750 μ in diameter; epidermis 15 μ; cuticle thin; chlorenchym of uniform globose cells compactly arranged and surrounding in each quarter-section an air-passage with diaphragms of 5–6 lobed star-shaped cells. (Plate I, fig. 1.)

Subalpine brook bank: light 0.03; available water 25–30%; humidity 60–85%; temperature 47°–69°.

SAXIFRAGA PUNCTATA: diphotophyll 450 μ; epidermis, upper 30 μ, lower 20 μ; cuticle thin; chlorenchym (400 μ) 1 row prolate palisade cells 70 μ; a region of loose subglobose and irregular cells merging into large elongated cells and large air-spaces. (Plate II, fig. 1.)

Since most of the hydrophytes secured had both submerged and aerial leaves, or else aquatic and amphibious forms, they have been discussed under "Polydemic Species." Of the two here mentioned, *Isoetes* is typically a submerged plant. The physiological processes of submerged leaves are of the simplest sort, since the assimilative cells are in direct contact with their food supply. This fact, together with that of reduced transpiration and diffuse light, accounts for the undifferentiated structure of the chlorenchym. *Saxifraga punctata* is unusual in being an amphibious plant which grows in the shade. The effect of the reduced light is seen in the small amount of palisade tissue, which comprises but 17 per cent. of the chlorenchym, while the presence of abundant water and great humidity is apparent in the character of the sponge tissue. Adaptations to prevent the stagnation of the sap current are necessary under these conditions. This is attained in the great increase of transpiring

surface found in the large-celled lacunose sponge. The region of small closer sponge cells doubtless represents the transformation of ancestral palisade cells into sponge cells, since the saxifrages are typically sun-plants.

MESOPHYTIC TYPES

SCIOPHYTA (SHADE PLANTS)

Subalpine brook banks: light 0.03; available water 25–30%; humidity 60–85%; temperature 47°–69°.

LIMNORCHIS STRICTA: spongophyll 350 μ; epidermis, upper 125 μ, lower 50 μ, both somewhat wavy; cuticle 2 μ; chlorenchym (175 μ) irregular sponge-like cells loosely arranged throughout the leaf, but more closely in the upper part than in the lower. (Plate II, fig. 2.)

VAGNERA LEPTOSEPALA: diphotophyll 150 μ; epidermis, upper 30 μ, lower 20 μ; cuticle 2 μ; chlorenchym (100 μ) 1 row globose to oblate palisade cells 25 μ; loose oblate sponge cells. (Plate II, fig. 3.)

Streptopus amplexifolius: upper epidermis 60 μ; upper cuticle 3 μ; surfaces slightly undulating.

EPILOBIUM ADENOCAULON: diphotophyll 100 μ; epidermis 15 μ; cuticle thin; chlorenchym (70 μ) 1 row of funnel and subglobose palisade cells 25 μ; loose oblate to globose sponge cells. (Plate II, fig. 4.)

Washingtonia obtusa: leaf 75 μ; epidermis wavy.

Asplenium filix-foemina: upper epidermis 20 μ.

Alpine rock-clefts: light 0.05; available water 12–17%; humidity 40–60%; temperature 30°–55°.

SAXIFRAGA DEBILIS: diphotophyll 270 μ; epidermis upper 25 μ, lower 20μ; cuticle thin; chlorenchym (225 μ) 1 lacunose row prolate palisade cells 75 μ, and a shorter row of subglobose cells; lacunose oblate sponge cells. (Plate II, fig. 5.)

Senecio carthamioides: leaf 325 μ.

CICUTA GRAYII: diphotophyll 275 μ; epidermis 30 μ; cuticle thin; chlorenchym (215 μ) 1–2 lacunose rows prolate palisade cells 75 μ, the lower row where present, shorter and more indefinite; lacunose oblate sponge cells. (Plate II, fig. 6.)

Spruce forests: light 0.03; available water 12–16%; humidity 40–70%; temperature 48°–72°.

ADOXA MOSCHATELLINA: diphotophyll 220 μ; epidermis, upper 25–50 μ, lower 20–30 μ; cuticle thin; chlorenchym (150 μ) 1 row subglobose palisade cells 40 μ; loose oblate sponge cells. (Plate II, fig. 7.)

Calypso boreale: tissues close; lower epidermis 40 μ; cuticle 5 μ; 1–2 rows palisade cells.

MONESES UNIFLORA: diphotophyll 250 μ; epidermis, upper 25 μ, lower 20 μ; chlorenchym (205 μ) 1–2 loose rows globose palisade cells 40 μ; lacunose globose and oblong sponge cells. (Plate II, fig. 8.)

PARIETARIA PENNSILVANICA: diphotophyll 100 μ; epidermis, upper 25 μ, lower 10 μ; cuticle thin; chlorenchym (65 μ) 1 loose row funnel palisade cells 32 μ; loose irregular to oblong sponge cells. (Plate II, fig. 9.)

Rosa sayii: palisade cells narrower.

Geranium richardsonii (sub-type): leaf 150 μ; epidermis, upper 20 μ, lower 15 μ; cuticle thin; chlorenchym (135 μ) 1 loose row funnel palisade cells 55 μ; lacunose oblate sponge cells. (Plate VI, fig. 3 *a*.)

Mertensia pratensis: epidermis, upper 35 μ, lower 25 μ; palisade cells clustered at lower ends.

Mertensia ciliata (light 0.01; available water 25–30%): leaf 200 μ; epidermis wavy, upper 30 μ, lower 20 μ; palisade cells 60 μ; clustered at lower ends; sponge very lacunose.

Actaea rubra (available water 18%): palisade cells 30–40 μ.

VIOLA PALUSTRIS: diphotophyll 180 μ; epidermis, upper 30 μ, lower 20 μ; cuticle thin; chlorenchym (130 μ) 1 loose row prolate palisade cells 60 μ; and 1 row of subglobose cells 25 μ; loose oblate sponge cells. (Plate II, fig. 10.)

Galium aparine (light 0.01): leaf 150 μ; epidermis 20 μ; palisade cells 50 μ; globose sponge cells.

Erodium cicutarium (light 0.01): lower epidermis very unequal, 15–50 μ; row of cells next to prolate palisade cells globose to prolate 25–40 μ.

Viola blanda (sub-type): leaf 190 μ; epidermis 40 μ; cuticle thin; chlorenchym (110 μ) 1 loose row prolate palisade cells 40 μ, individual cells frequently divided into two; 1 row of globose cells; loose globose to oblate sponge cells.

ARNICA CORDIFOLIA: diphotophyll 350 μ; epidermis, upper 25 μ,

lower 20 μ; cuticle, upper 2 μ, lower thin; chlorenchym (305 μ) 2 lacunose rows prolate palisade cells 75 μ; lacunose star-shaped sponge cells. (Plate II, fig. 11.)

Polemonium speciosum: leaf 325 μ; epidermis 20 μ; cuticle thin.

Erigeron superbus: leaf 300 μ; second row of palisade cells indefinite, transforming into sponge cells.

Open spruce: light 0.1; available water 12–16%; humidity 40–70%; temperature 48°–72°.

GYROSTACHYS STRICTA: spongophyll 350 μ; epidermis, upper 50 μ, lower 30 μ; cuticle 5 μ; chlorenchym (270 μ) uniform subglobose cells. (Plate III, fig. 1.)

Zygadenus elegans: leaf 300 μ; epidermis 50 μ.

CASTILLEIA SULPHUREA: diplophyll 160 μ; epidermis 15 μ; cuticle thin; chlorenchym (130 μ) 1 loose row subglobose to prolate cells next to either epidermis; central loose oblate and prolate cells. (Plate III, fig. 2.)

Castilleia sp.: leaf 200 μ; epidermis 20 μ.

CASTILLEIA CONFUSA: diphotophyll 190 μ; epidermis 20 μ; cuticle thin; chlorenchym (150 μ) 1 close row prolate palisade cells 60 μ; close subglobose sponge cells.

The spongophyll is the characteristic form of monocotyledonous types. The very large-celled epidermis of *Limnorchis, Streptopus* and *Vagnera* is probably an adaptation for the furthering of transpiration. It is extremely well developed in these three wet-soil shade-plants, and is also large for other shade-plants living in a rather high percentage of soil-water. *Calypso boreale,* although placed with *Adoxa moschatellina* as a shade-plant, has a thick cuticle, indications of two rows of palisade cells, and a more compact structure. These facts indicate that the ancestors of *Calypso* were sun-plants, and that hereditary structure has not as yet yielded to any extent to the influence of shade conditions.

The type of leaf most common among dicotyledonous shade-plants is that of *Parietaria pennsilvanica* and *Geranium richardsonii.* Adaptations for an increase of transpiration are the thin cuticle, and the loose sponge tissue, as well as the wavy epidermis and surfaces. The effects of the diffuse light are to be found in the thinness of the leaf, the reduction in chloroplasts and palisade cells, and the oblate shape of the sponge cells. *Erodium cicutarium,* which is a ruderal plant growing in moist sunny situations, is similar

to *Viola palustris,* a shade-mesophyte. The difference between them consists in their respective amounts of palisade tissue, *Erodium* having two rows and *Viola* one and a half rows. This indicates that *Viola* is adapting itself to shade conditions. *Saxifraga debilis* and *Senecio carthamioides* with a light value of 0.05 have one and a half rows of palisade cells very loosely arranged. *Arnica cordifolia* and *Cicuta grayii* still show hereditary characteristics in a somewhat thickened upper cuticle and two rows of palisade cells. These latter, however, are evidently in a process of reduction, since the second row is shorter and fewer-celled than the upper. At the same time an adaptation to a moist shady habitat is to be found in the looseness of all tissues.

HELIOPHYTA (SUNLIGHT PLANTS)

Brook banks and bogs: light 1; available water 25–58%; humidity 40–70%; temperature 40°–75°.

CLEMENTSIA RHODANTHA: diphotophyll 850 μ in center, 450 μ at edges; epidermis 40 μ; cuticle, upper 2 μ, lower thin; chlorenchym (570 μ in center, 370 μ at edges) lacunose chains of prolate cells 85 μ, more numerous next to upper epidermis; central subglobose and oblong cells. (Plate III, fig. 3.)

Sedum roseum: leaf 750 μ in center.

Claytonia megarrhiza (alpine rock-cleft; available water 12–17%): leaf 750 μ in center; epidermis 50 μ; smaller central region.

LILIUM MONTANUM: diphotophyll 400 μ; epidermis, upper 40 μ, lower 30 μ; cuticle, upper 5 μ, lower 3 μ; chlorenchym (330 μ) 1 close row prolate and prolobate palisade cells 80 μ (in the proportion of 1 to 2); lacunose irregular and star-shaped sponge cells. (Plate III, fig. 4.)

Anemone globosa (aspens, early spring): leaf 300 μ; lower epidermis 40 μ; cuticle 5 μ; sponge cells closer.

Dodecatheon pauciflorum: leaf 350 μ; upper epidermis 30 μ; palisade cells all prolate 75 μ.

Gentiana frigida (sub-type): leaf 350 μ; epidermis 30 μ; chlorenchym (290 μ) 2 loose rows prolate palisade cells 40 μ; lacunose subglobose and oblong sponge cells.

SENECIO CROCATUS: diphotophyll 400 μ; epidermis 25 μ; cuticle 5 μ; chlorenchym (350 μ) 2 loose rows prolate palisade cells 75 μ; lacunose irregular sponge cells. (Plate III, fig. 5.)

Elephantella groenlandica: leaf 300 μ.

Alpine and subalpine meadows: light 1; available water 12–17%; humidity 30–65%; temperature 40°–75°.

VERONICA WORMSJOLDII: diphotophyll 210 μ; epidermis 15 μ; cuticle 2 μ; chlorenchym (180 μ) 2–3 loose rows prolate palisade cells 40 μ; loose irregular and oblong sponge cells. (Plate III, fig. 6.)

Spergula sp.: leaf 300 μ; epidermis 20 μ; palisade cells 50 μ.

Cerastium strictum: leaf 250 μ; epidermis 25 μ; palisade cells 50 μ.

Primula angustifolia: leaf 250 μ; epidermis 25 μ; palisade cells 50 μ.

Pedicularis parryi: leaf 250 μ; epidermis, upper 30 μ, lower 20 μ with papillae.

Alsine baicalensis: epidermis, upper 25 μ, lower 20 μ; subglobose sponge cells.

Halerpestes cymbalaria: leaf 250 μ; epidermis 25 μ; palisade cells 50 μ.

Pedicularis canadensis: epidermis, upper 25 μ; lower 20 μ with papillae.

Alsine longipes: leaf 175 μ; epidermis, upper 25 μ, lower 20 μ; 1–2 rows of palisade cells, the second more indefinite.

CAMPANULA UNIFLORA: diphotophyll 225 μ; epidermis, upper 50 μ, lower 25 μ; chlorenchym (150 μ) 1 compact row prolate palisade cells 50 μ; close subglobose sponge cells.

AGOSERIS AURANTIACA: diplophyll 300 μ; epidermis 25 μ; cuticle 3 μ; chlorenchym (250 μ) 1 lacunose row prolate palisade cells 50–75 μ next to either epidermis; central loose irregular sponge cells. (Plate III, fig. 7.)

Agoseris glauca: leaf 350 μ; epidermis 35 μ.

Senecio chloranthus: leaf 350 μ; cuticle 5 μ; epidermis 35 μ.

Pericome caudata: leaf 250 μ; epidermis 20 μ; cuticle 2 μ.

Erigeron minor (sub-type—available water 9–14%): leaf 250 μ; epidermis 25 μ; cuticle 5 μ; chlorenchym (200 μ) 2 loose irregular rows prolate palisade cells 30–40 μ next to either epidermis; central subglobose cells.

Erigeron subtrinervis: tissues closer.

Erigeron conspicuus.

DRABA STREPTOCARPA: diphotophyll 400 μ; epidermis 25 μ; cuticle

4 μ; chlorenchym (350 μ) 3–4 loose rows subglobose to prolate palisade cells 50 μ; loose subglobose sponge cells. (Plate III, fig. 8.)

Besseya plantaginea: 2–3 rows palisade cells 50–60 μ.

Besseya alpina: leaf 300 μ; palisade cells 35–50 μ.

Draba aureiformis (available water 9–14%): closer sponge.

Pirola chlorantha (light 0.03).

Draba sp.: leaf 325 μ

Androsace subumbellata: palisade cells 60–75 μ; sponge cells irregular and more loosely arranged.

SALIX SAXIMONTANA: diphotophyll 225 μ; epidermis 25 μ; cuticle, upper 5 μ, lower 2 μ; chlorenchym (175 μ) 3 compact rows prolate palisade cells 40 μ; loose sponge cells. (Plate IV, fig. 1.)

Salix pseudolapponum: upper epidermis 20 μ; cuticle 2 μ; third row of palisade looser 30 μ; close somewhat prolate sponge cells.

Salix nuttallii: compact somewhat prolate sponge cells.

POPULUS TREMULOIDES: diphotophyll 200 μ; epidermis 15 μ; cuticle 2 μ with papillae, smaller and more scattered on lower surface; chlorenchym (170 μ) 2 close regular rows prolate palisade cells 45 μ; loose triangular and oblate sponge cells. (Plate IV, fig. 2.)

Rhus trilobata: no papillae; sponge somewhat prolate.

Geum oregonense: leaf 250 μ; epidermis, upper 35 μ, lower 20 μ; chlorenchym (195 μ) 1–2 rows palisade cells 50–100 μ; sponge cells close and subglobose; no papillae.

Polygonum viviparum: leaf 350 μ; cuticle 2 μ.

Betula glandulosa (sub-type): diphotophyll 200 μ; epidermis 25 μ; cuticle 2 μ; chlorenchym (150 μ) 2 rows prolate palisade cells 30 μ, the first compact, the second looser; lacunose oblong sponge cells.

Betula occidentalis.

Aquilegia coerulea: upper epidermis 30 μ; papillae on both surfaces.

Fragaria pumila: leaf 175 μ; epidermis, upper 35 μ, lower 25 μ; tissues closer.

Aquilegia brevistylis (sub-type): leaf 200 μ; epidermis, upper 30 μ with papillae, lower 25–50 μ, wavy; cuticle 2 μ; chlorenchym (140 μ) 2–3 compact rows prolate palisade cells 30 μ; close globose sponge cells.

Compared with shade-mesophytes, sun-mesophytes show a greater development of palisade tissue either in compactness of the cells, or an increase in length of cell or number of rows. Since for the two groups, the chief difference in the habitat is that of light, it is plain that light must be the most directly concerned with the palisading of the leaf. It is also noticeable that within the sciophytes as a group there is a definite relation between the amount of soil-water and the sponge tissue, the latter increasing in looseness as the former increases in amount. A third fact suggested by a comparative study of the group is that of the stability of composites. *Senecio pudicus,* though a shade-plant, has the structure of a heliophyte. The leaves of the *Agoseris aurantiaca* group, which are all composites, have the structure of vertically placed rather xerophytic leaves. They have adapted themselves, however, to considerable water in the soil, by loose tissues, and *Senecio chloranthus* has rudimentary sponge cells. This, on the other hand, has not taken place among the erigerons: *E. minor, E. subtrinervis,* and *E. conspicuus,* which, though living in 20–25% of soil-water, can scarcely be distinguished from *E. speciosus* and *Aster geyeri* in a xerophytic group with considerably less water.

XEROPHYTIC TYPES

Alpine and subalpine meadows: light 1; available water 12–17%; humidity 30–65%; temperature 40°–65°; 50°–75°.

ANTENNARIA SP.: diphotophyll 150 μ; epidermis 15 μ; cuticle thin; chlorenchym (120 μ) 1 compact row prolate palisade cells 45 μ; compact globose sponge cells. (Plate IV, fig. 3.)

Antennaria mucronata.

Antennaria nardina: leaf 125 μ.

Antennaria imbricata: epidermis 20 μ, very wavy.

Antennaria parvifolia: epidermis 20 μ, wavy.

DRYAS OCTOPETALA: diphotophyll 250 μ; epidermis 20 μ; cuticle 2 μ; chlorenchym (210 μ) 3–4 compact rows prolate palisade cells 35 μ; loose irregular sponge cells.

PSEUDOCYMOPTERUS MONTANUS PURPUREUS: diphotophyll 225 μ; epidermis 25 μ; cuticle thin; chlorenchym (175 μ) 2 compact rows prolate palisade cells 50 μ; compact subglobose sponge cells. (Plate IV, fig. 7.)

Fragaria glauca: sponge loose.

Potentilla rubricaulis: leaf 175 μ; lower epidermis 15 μ; loose sponge cells.

Potentilla pulcherrima: (like preceding).

Potentilla minutifolia: leaf 175 μ; lower epidermis 15 μ; cuticle 5 μ; chlorenchym (135 μ) 2–3 rows palisade cells 35 μ.

Potentilla monspeliensis: cuticle 2 μ; sponge loose.

Potentilla bipinnatifida: leaf 125 μ; epidermis 15 μ; cells 25 μ.

Sibbaldia procumbens.

Gravel, half gravel, mesa, etc.: light 1; available water 2.5–7.5%; temperature and humidity variable for the various locations.

PHACELIA LYALLII: diphotophyll 250 μ; epidermis, upper 20 μ, lower 15 μ; cuticle thin; chlorenchym (215 μ) 1 close row prolate palisade cells 75 μ; loose irregular sponge cells. (Plate IV, fig. 4.)

Phacelia heterophylla: closer sponge.

Phacelia glandulosa: leaf 225 μ.

Pulsatilla hirsutissima (sub-type): leaf 300 μ; epidermis upper 35 μ, lower 30 μ; cuticle thin; chlorenchym (235 μ) 1 close regular row prolate palisade cells 100 μ; close subglobose sponge cells.

Pedicularis procera (sub-type): leaf 250 μ; epidermis, upper 30 μ, lower 20 μ; cuticle 2 μ; papillae on lower surface, chlorenchym (200 μ) 1 close row prolate palisade cells 100 μ; loose irregular sponge cells. (Plate IV, fig. 5.)

HEUCHERA PARVIFOLIA: diphotophyll 250 μ; epidermis, upper 25 μ, lower 20 μ; cuticle 5 μ; chlorenchym (205 μ) 2–4 close rows prolate palisade cells 25–40 μ; loose subglobose sponge cells. (Plate IV, fig. 6.)

Heuchera hallii: epidermis 25 μ; cells close.

MIRABILIS OXYBAPHOIDES: diphotophyll 475 μ; epidermis, upper 35 μ, lower 25 μ; cuticle thin; chlorenchym (415 μ) 1 compact row prolate palisade cells 175 μ; loose irregular sponge cells.

GENTIANA AFFINIS: diphotophyll 350 μ; epidermis, upper 35 μ, lower 30 μ; cuticle 5 μ; chlorenchym (285 μ) 2 close irregular rows prolate palisade cells 75 μ; loose irregular sponge cells. (Plate IV, fig. 8.)

Coleanthus congestum: leaf 300 μ; epidermis, upper 25 μ, lower 15 μ; cuticle 2 μ; closer sponge.

Kuhnia gooddingii: leaf 300 μ; epidermis, upper 20 μ, lower 15 μ; palisade cells 60 μ.

Senecio eremophilus (sub-type): leaf 350 μ; epidermis, upper

35 μ, lower 25 μ; cuticle 2 μ; chlorenchym (290 μ) 2 regular close rows prolate palisade cells 60 μ; close irregular sponge cells.

Carduus scopulorum: leaf 300 μ epidermis, upper 30 μ, lower 20 μ; palisade cells 50 μ.

CASTILLEIA OCCIDENTALIS: spongophyll 200 μ; epidermis 25 μ; cuticle 2 μ; chlorenchym (150 μ) close subglobose cells.

TOUTEREA MULTIFLORA: diplophyll 500 μ; epidermis 25 μ; cuticle 2 μ; chlorenchym (450 μ) 2 compact rows overlapping prolate palisade cells next to either epidermis 100 μ, central close oblong cells. (Plate IV, fig. 9.)

Mentzelia nuda: leaf 400 μ; palisade cells 75 μ.

Physaria acutifolia: central compact subglobose cells.

Tetraneuris lanata: cuticle 5 μ; palisade cells 75 μ.

Tetraneuris glabriuscula: epidermis 60 μ; cuticle 10 μ.

Aragalus multiceps: leaf 425 μ; epidermis 35 μ; cuticle, 15 μ.

Mentzelia albicaulis (sub-type): leaf 400 μ; 1–2 rows palisade cells next to either epidermis, the second row oblobate and merging into the central loose star-shaped cells.

SOLIDAGO PALLIDA: diplophyll 275 μ; epidermis 25 μ; cuticle 5 μ; chlorenchym (225 μ) 2–4 close rows prolate palisade cells 30 μ, next to either epidermis; central subglobose to oblate water-storage cells 35% of chlorenchym. (Plate V, fig. 1.)

Artemisia dracunculoides: cuticle 7 μ.

Machaeranthera cichoracea: leaf 325 μ; epidermis 30 μ.

Pseudocymopterus montanus: cuticle thin; 1 row prolate cells next to lower epidermis.

Erigeron pinnatisectus (sub-type): diplophyll 375 μ; epidermis 25 μ; cuticle 7 μ; chlorenchym (325 μ) 2–4 compact irregular rows prolate palisade cells 50–75 μ, next to either epidermis; central water-storage cells 25% of chlorenchym.

Artemisia scouleriana.

Sideranthus spinulosum: leaf 325 μ; epidermis 30 μ; cuticle 10 μ.

Erigeron multifidus: leaf 500 μ.

Thelesperma gracile: leaf 500 μ; epidermis 40 μ; water-storage tissue 35% of chlorenchym.

Laciniaria punctata: leaf 500 μ; epidermis 40 μ.

Gilia aggregata: leaf 500 μ; epidermis 50 μ; cuticle 4 μ.

Hymenopappus luteus (sub-type): leaf 500 μ; epidermis 25 μ; cuticle 7 μ; edges of leaf rolled towards each other, inner surface showing great reduction of palisade.

Solidago missouriensis (sub-type): diplophyll 325 μ; epidermis 30 μ; cuticle 5 μ; chlorenchym (265 μ) 2–4 close rows prolate palisade cells 30–50 μ, next to either epidermis (usually fewer next to lower); central water-storage cells 27% of chlorenchym.

Solidago extraria.

Solidago oreophila: leaf 250 μ.

Solidago decumbens: leaf 300 μ.

Solidago multiradiata.

Anogra pallida: leaf 375 μ.

Kuhniastera purpurea.

Erigeron glandulosus: leaf 350 μ; epidermis 40 μ; cuticle 10 μ.

Paronychia pulvinata: leaf 350 μ; cuticle 3 μ.

Oreoxis humilus: leaf 400 μ; epidermis 50 μ; cells 50–75 μ.

Oreoxis alpina: leaf 375 μ; epidermis 40 μ; cuticle 7 μ; 2 rows palisade cells next to either epidermis 50–75 μ.

MERTENSIA LINEARIS: diplophyll 350 μ; epidermis 45 μ; cuticle 5 μ; chlorenchym (260 μ) 2–3 rows prolate palisade cells 25–50 μ, next to either epidermis; central subglobose to oblate water-storage cells 40% of chlorenchym. (Plate IV, fig. 10.)

Plantago purshii: leaf 275 μ; epidermis 35 μ; cuticle 3 μ.

Argemone intermedia: leaf 300 μ; cuticle 3 μ; water-tissue 25% of chlorenchym.

Mertensia lateriflora: epidermis 25 μ; cuticle 3 μ.

Mertensia alpina: epidermis 25 μ; cuticle 3 μ.

Oreocarya virgata: epidermis 35 μ.

Oreocarya fruticosa: epidermis 25 μ; cuticle 8 μ.

Erigeron canus: water-storage tissue 25% of chlorenchym.

Erigeron flagellaris (sub type): leaf 225 μ; epidermis 25 μ; cuticle 5 μ; water-storage tissue 30% of chlorenchym.

Erigeron pumilus: leaf 250 μ; epidermis 35 μ; cuticle 7 μ.

Lithospermum linearifolium (sub-type): leaf 350 μ; epidermis 25 μ; cuticle thin; chlorenchym (300 μ) 2 rows prolate palisade cells 50 μ next to upper epidermis, 1 row next to lower epidermis; intermediate oblate water-storage cells 50% of chlorenchym.

Lithospermum parviflorum.

Onagra strigosa (sub-type): leaf 325 μ; epidermis 25 μ; cuticle thin; chlorenchym (275 μ) 2–3 rows prolate cells 60–75 μ next to upper epidermis, 1 row 40–50 μ next to lower epidermis; central irregular cells.

Potentilla coloradensis: leaf 200 μ; cuticle 5 μ; cells 40–50 μ.

Monarda menthifolia (sub-type): leaf 250 μ; epidermis 25 μ; cuticle 4 μ; chlorenchym (200 μ) 1 row prolate palisade cells 75–100 μ next to upper epidermis, 1 row 40–50 μ next to lower epidermis; central triangular cells. (Plate VIII, fig. 7 *a.*)

Eriogonum annuum: central cells compact subglobose and prolate.

Hedeoma nana.

Meriolix serrulata (sub-type): leaf 250 μ; epidermis 25 μ; cuticle 5 μ; chlorenchym (200 μ) 2 loose rows prolate palisade cells 50 μ next to either epidermis; central subglobose cells 25% of chlorenchym.

Lappula cupulata: leaf 200 μ; cuticle thin.

Gaura parviflora: leaf 200 μ; cuticle 2 μ; central tissue 20% of chlorenchym.

CASTILLEIA INTEGRA: staurophyll 375 μ; epidermis 20 μ; cuticle 2 μ; chlorenchym (335 μ) compact subglobose and prolate cells 25–75 μ.

ASTRAGALUS DRUMMONDII: staurophyll 225 μ; epidermis 25 μ; cuticle 5 μ; chlorenchym (175 μ) compact prolate cells 50 μ, irregularly arranged. (Plate V, fig. 5.)

Arabis oxyphylla: leaf 200 μ; epidermis 20 μ; cells 25 μ.

Pentstemon humilus.

Cleome serrulata: epidermis 35 μ; cuticle 2 μ.

Chrysopsis amplifolia.

Chrysopsis sp.

Trifolium dasyphyllum: cuticle 2 μ; papillae on either surface.

Eriogonum effusum.

Gymnolomia multiflora: cells arranged in more regular rows, the upper 60 μ, the lower 40 μ.

Macronema pygmaeum (sub-type): leaf 300 μ, looser.

Aragalus lamberti: leaf 350 μ; epidermis 35 μ; cells loose 50–75 μ.

ARABIS FENDLERI: staurophyll 325 μ; epidermis 35 μ; cuticle 7 μ; chlorenchym (255 μ) close irregular rows prolate palisade cells 25–50 μ. (Plate V, fig. 6.)

Anogra coronopifolia: epidermis wavy.

Thelypodium micranthum: leaf 250 μ; epidermis 20 μ; cuticle 5 μ.

Lesquerella montana: cuticle 2 μ.

Erysimum elegans: leaf 375 μ.

Erigeron leucotrichus (sub-type): staurophyll 350 μ; epidermis 50 μ; cuticle 10 μ; chlorenchym (250 μ) loose prolate palisade cells 50 μ.

Astragalus adsurgens: leaf 275 μ; epidermis 40 μ.

Erigeron elatior.

Erigeron debilis: leaf 250 μ.

Aster geyeri: cuticle 5 μ.

Aster frondosus: leaf 325 μ; cuticle 5 μ.

Thermopsis rhombifolia (sub-type): leaf 325 μ; epidermis 30 μ; cuticle 2 μ; cells close and uniform.

Epilobium paniculatum (sub-type): staurophyll 300 μ; epidermis 15 μ; cuticle thin; chlorenchym (270 μ) compact prolate palisade cells 50–75 μ; scattered water-storage cells.

Eriogonum alatum: leaf 350 μ; epidermis 25 μ; cuticle 2 μ.

Malvastrum coccineum: epidermis 25 μ; cuticle 2 μ.

Ambrosia psilostachya (sub-type): staurophyll 175 μ; epidermis 25 μ; cuticle thin; surfaces wavy; chlorenchym (125 μ) loose prolate cells 30 μ.

Coleanthus albicaule: leaf 150 μ; cuticle 2 μ.

Chrysopsis villosa: cuticle 5 μ.

PENTSTEMON UNILATERALIS: staurophyll 400 μ; epidermis 35 μ; cuticle 7 μ; chlorenchym (330 μ) close subglobose to prolate palisade cells 30–50 μ, arranged more or less regularly. (Plate V, fig. 7.)

Pentstemon brandegei.

Pentstemon brandegei prostratus.

Pentstemon torreyi: leaf 350 μ; cells 30–65 μ, the longer, as a rule, next to upper epidermis.

Pentstemon hallii nana: leaf 425 μ.

ASCLEPIODORA DECUMBENS: staurophyll 300 μ; epidermis 25 μ; cuticle 5 μ; chlorenchym (250 μ) regular rows compact prolate palisade cells 40–70 μ, the longer next to upper epidermis. (Plate V, fig. 2.)

Kuhniastera oligophylla: leaf 350 μ.

Allionia hirsuta (transition to *Bahia dissecta* type): leaf 350–400 μ; palisade cells 4–6 regular rows, the upper 100 μ, the lower 50 μ.

BAHIA DISSECTA: staurophyll 700 μ; epidermis 25 μ; cuticle 2 μ; chlorenchym (650 μ) 4–5 close rows prolate palisade cells, the first long and narrow 200 μ, the next 2 or 3 broader, and the last 100 μ, narrow and oblobate. (Plate V, fig. 8.)

Senecio taraxacoides (sub-type): staurophyll 900 μ; epidermis, upper 50 μ, lower 40 μ; cuticle 4 μ; chlorenchym (810 μ) 5 irregular rows prolate palisade cells, the upper 2 rows 175 μ each, the lowermost 100 μ.

GRINDELIA SQUARROSA: staurophyll 375 μ; epidermis 25 μ; cuticle 5 μ; chlorenchym (325 μ) prolate palisade cells 30 μ, loosely and irregularly arranged; frequent transverse bands or isolated areas of water-storage tissue, of subglobose and polygonal cells. (Plate V, fig. 3.)

Psoralea lanceolata: water-storage cells large, oblong ones perpendicular to the surface.

Helianthus pumilus: leaf 400 μ; cells 50–75 μ.

Helianthus petiolaris: leaf 300 μ; cuticle 3 μ; cells 50 μ.

Helianthus scaberrimus (sub-type): leaf 650 μ; epidermis 35 μ; cuticle 5 μ; cells 50–125 μ, the lower ones oblobate. (Plate V, fig. 4.)

Transitions from mesophytes to xerophytes are represented by those of the latter with diphotic leaves. These differ from mesophytes in closeness of tissues and increased amounts of palisade tissue. The true xerophytes fall into two broad groups according to leaf structure: those consisting entirely of palisade cells, with water-storage tissue where present arranged in transverse bands,—the staurophyll type; and those with hypodermal palisade cells and central region of sponge or water-storage tissue,—the diplophyll type. Xerophytes are found in situations characterized by small amounts of soil-water, high light intensities, and low humidities, whether the latter are brought about by high temperatures, as in the foothills, or by altitude, as in the alpine region. Adaptations in the leaf then must be in the direction of protection against harmful transpiration and over-illumination. Diplophyll and staurophyll types together with thick cuticles and woolly coverings in single instances, are the results. The cuticle, hairs, compactness of tissues and presence of water-storage tissue control transpiration, while abundance of chloroplasts, long palisade cells or numerous compact rows and hairs regulate the light. The presence of the isophotic structure in leaves that are not vertically placed, but are normally horizontal, is clearly due to the effect of reflected light and heat, since such leaves are found in situations where such factors are present. Another point of interest brought out by a study of this

group is that alpine and foothill plants are so frequently grouped under the same types. Such plants are exposed to similar amounts of soil-water and of light as well as to low humidities, the latter however from a different cause for each situation—alpine humidity being low because of decreased air-pressure, and that of the foothills on account of the heat and radiation. Temperature is the only variable factor, being high for the foothills and low for the alpine region. This indicates that temperature is of less importance than other physical factors in determining leaf structure.

By far the larger number of composites are found among the xerophytic types. The *Antennaria* type is narrower leaved than the majority of xerophytes, and has but little palisade tissue. This is due to the thick covering of hairs on either surface. It has been found that such a covering acts as a screen to light, and that the chlorenchym beneath has the structure typical of a shade-leaf. In some cases the palisade is very loose under such conditions, especially where the leaf is rather thick, as in *Rydbergia grandiflora.* This is also evident in *Aragalus lamberti* and *Macronema pygmaeum,* which vary from the type in possessing a looser arrangement of the chlorenchym cells, and a woolly coating of hair. In other cases, as in *Lesquerella,* a dense covering of stellate hairs by reducing transpiration permits thinness in the cuticle.

V. Discussion of Polydemic Species

The polydemic species have been grouped into hydrophytes, mesophytes and xerophytes according to the normal habitat of the species considered. The form occupying the normal habitat is taken as the type, and is described in connection with its physical factors. For the other forms only the points of difference between them and the type, either in physical factors or in structure, are noted. Following each form is a summary of the differences of both factors and structure with reference to the type. Abbreviations for this have been used as follows: " C," Chlorenchym; " P," Palisade; " S," Sponge; the plus and minus signs have been used to show increase or decrease with reference to the type, upon which the percentages are also based.

HYDROPHYTA

Batrachium aquatile

SUBMERGED: light —; available water 100%; humidity 100%; temperature 40°–65°: linear spongophyll, short diameter 300 μ, long diameter 540 μ; epidermis 15 μ; cuticle thin; chlorenchym (270 μ) of compact globose and polygonal cells surrounding two irregular air-passages. (Plate I, fig. 2 *a.*)

AMPHIBIOUS (dwarf): light 1; available water 58%; humidity 50–70%: diphotophyll short diameter 240 μ, long diameter 400 μ; chlorenchym (210 μ) 1 row prolate palisade cells 40 μ; globose sponge cells with one regular layer next to lower epidermis. (Plate I, fig. 2 *b.*)

Submerged	C. 270 μ	P. 0 μ	S. 270 μ
Amphibious	C. 210 μ	P. 40 μ	S. 170 μ
	—60 μ	+40 μ	—100 μ

Light +; water —42%; humidity —(30–50%); temperature the same.

Callitriche bifida

SUBMERGED: light —; available water 100%; humidity 100%; temperature 40°–65°: diphotophyll, lenticular in cross section, 100 μ through center, 40 μ at edges; epidermis 15 μ; cuticle thin; chlorenchym (70 μ) 1 row globose cells 15 μ, connected with lower epidermis by groups of similar cells with air-spaces between each group. (Plate I, fig. 3 *a.*)

AMPHIBIOUS (dwarf): light 1; available water 58%; humidity 50–70%: diphotophyll 150 μ; epidermis 12 μ; chlorenchym (126 μ) 1 row prolate palisade cells 50 μ; compact globose sponge cells. (Plate I, fig. 3 *b.*)

Submerged	C. 70 μ	P. 0 μ	S. 70 μ
Amphibious	C. 126 μ	P. 50 μ	S. 76 μ
	+56 μ	+50 μ	+6 μ

Light +; water —42%; temperature the same; humidity —(30–50%).

Hippuris vulgaris

SUBMERGED: light —; available water 100%; humidity 100%; temperature 40°–65°: spongophyll, lenticular in cross section, 175 μ in center, 40 μ at edges; epidermis 10 μ; cuticle thin; chlor-

enchym (155μ) 1 row globose cells 30μ, lining the epidermis and joined at intervals across the leaf by similar cells with air-passages between. (Plate I, fig. 4 *a*.)

AERIAL: light 1; humidity 80–90%: staurophyll 450μ; epidermis 15μ; chlorenchym (420μ) chains of prolate cells 50μ, traversing the leaf, close in the palisade area except for the stomatal air chambers, loose and more irregular in the sponge region. (Plate I, fig. 4 *b*.)

Submerged	C. 155μ	P. 0μ	S. 155μ
Aerial	C. 420μ	P. 420μ	S. 0μ
	$+265\mu$	$+420\mu$	-155μ

Light +; water and temperature the same; humidity —(10–20%).

AMPHIBIOUS (dwarf): light 1; available water 58%; humidity 50–70%: similar to the aerial leaf in structure although the plant is exceedingly dwarfed.

Light +; water —42%; temperature the same; humidity —(30–50%).

Sparganium angustifolium

FLOATING: light 1; available water 100%; humidity 100%; temperature 40°–65°: diphotophyll, lenticular in cross section; 600μ in center, 200μ towards edges; epidermis 15μ; cuticle thin; chlorenchym (570μ) 3–4 compact rows prolate palisade cells 30μ; 1 row globose and oblong sponge cells 15μ; 3 air-passages each side of midrib, crossed frequently by diaphragms of 5–6 lobed star-shaped cells, and separated from each other by partitions of parenchyma cells containing bundles. (Plate I, fig. 5 *a*.)

AMPHIBIOUS (dwarf): light 1; available water 58%; humidity 50–70%: plant greatly dwarfed but no change in leaf structure.

SUBMERGED: light —: leaf 500μ; epidermis 35μ; chlorenchym (430μ) a one-celled layer of oblate cells next to the epidermis 15μ; diaphragm cells 6–7 lobed elongated horizontally. (Plate I, fig. 5 *b*.)

Floating	C. 570μ	P. 3–4 rows,	120μ	S. 15μ
Submerged	C. 430μ	P. 1 row,	15μ	S. 15μ
	-140μ	— (2–3) rows,	-105μ (97%)	0
Floating			Air spaces, 435μ	
Submerged			Air spaces, 400μ	
			-35μ	

Light decreased; water, humidity and temperature unchanged.

DEEPLY SUBMERGED: light —: leaf 290 μ; epidermis 25 μ; chlorenchym (150 μ) a one-celled layer of oblate cells next to the epidermis 15 μ, looser than the preceding; diaphragm cells elongated and disappearing. (Plate I, fig. 5 *c*.)

Floating	C. 570 μ	P. 3-4 rows,	120 μ	S. 15 μ
Deeply submerged	C. 150 μ	P. 1 row,	15 μ	S. 15 μ
	— 420 μ	— (2-3) rows,	— 105 μ (97%)	0

Floating	Air spaces, 435 μ
Deeply submerged	Air spaces, 120 μ
	— 315 μ

Light decreased; other factors unchanged.

MESOPHYTA

SCIOPHYTA

Clematis ligusticifolia

FOOTHILL THICKET: light 0.0125; available water 11%; humidity 38–80%; temperature 53°–85°: diphotophyll 125 μ; epidermis wavy, upper 25–30 μ, lower 20–30 μ; cuticle thin; chlorenchym (90 μ) 1 row funnel palisade cells 25 μ; loose globose sponge cells.

FOOTHILL SUNLIGHT: light 1; available water 11%; humidity 28–77%; temperature 57°–89°: diphotophyll 200 μ; epidermis, upper 25 μ, long flat cells, lower 20 μ; cuticle 3 μ; chlorenchym (155 μ) 1 row prolate palisade cells 75 μ; irregular sponge cells.

Thicket	C. 90 μ	P. 1 row, 25 μ	S. 65 μ
Sunlight	C. 155 μ	P. 1 row, 75 μ	S. 80 μ
	+ 65 μ	+ 50 μ (200%)	+ 25 μ (38%)

Light 80/1; water unchanged; humidity —(3–10%); temperature + 4°.

Chenopodium fremontii

FOOTHILL THICKET: light 0.0125; available water 11%; humidity 38–80%; temperature 53°–85°: diphotophyll 80 μ; epidermis 15 μ; cuticle thin; chlorenchym (50 μ) 1 row subglobose and funnel cells 20 μ; oblate sponge cells.

FOOTHILL SUNLIGHT: light 1; available water 4.5–7.5%; humidity 28–77%; temperature 57°–89°: diphotophyll 225 μ; epidermis 25 μ; cuticle 4 μ; chlorenchym (175 μ) 1 row prolate palisade cells 65 μ; close globose sponge cells.

Thicket	C. 50 μ	P. 1 row, 20 μ	S. 30 μ
Sunlight	C. 175 μ	P. 1 row, 65 μ	S. 110 μ
	+ 125 μ	+ 45 μ (225%)	+ 80 μ (266%)

Light 80/1; water —(3.5–6.5%); humidity —(3–10%); temperature + 4°.

Acer glabrum

SPRUCE SHADE: light 0.03; available water 12–16%; humidity 40–70%; temperature 48°–72°: diphotophyll 130 μ; epidermis 20 μ, lower epidermal cells with inner flat surface and outer very wavy; cuticle thin; chlorenchym (90 μ) 1 loose row prolate palisade cells 45 μ; loose triangular and oblate sponge cells. (Plate VI, fig. 1 *a*.)

THICKET SHADE: light 0.014; available water 15%: diphotophyll 110 μ; epidermis 15 μ; chlorenchym (75 μ) 1 row funnel palisade cells 30 μ; loose oblate sponge cells. (Plate VI, fig. 1 *b*.)

Spruce	C. 90 μ	P. 1 row, 45 μ	S. 45 μ
Thicket	C. 75 μ	P. 1 row, 30 μ	S. 45 μ
	— 15 μ	— 15 μ (33%)	0

Light ½; other factors unchanged.

HALF GRAVEL: light 1; available water 4.5–7.5%; humidity 30–65%; temperature 51°–76°: diphotophyll 225 μ; cuticle 3 μ; chlorenchym (175 μ) 1 close row prolate palisade cells 75 μ; rather close irregular and prolate sponge cells; numerous mucilage and crystal cells. (Plate VI, fig. 1 *c*.)

Spruce	C. 90 μ	P. 1 row, 45 μ	S. 45 μ
Half gravel ..	C. 175 μ	P. 1 row, 75 μ	S. 100 μ
	+ 85 μ	+ 30 μ (66%)	+ 55 μ (122%)

Light 33/1; water —(7.5–8.5%); humidity —(5–10%); temperature + (3°–4°).

Edwinia americana

SPRUCE SHADE: light 0.03; available water 12–16%; humidity 40–70%; temperature 48°–72°: diphotophyll 110 μ; epidermis, upper 20 μ, lower 15 μ; cuticle, upper 2 μ, lower thin; chlorenchym (75 μ) 1–2 rows prolate and prolobate palisade cells, first row 25 μ, second row 20 μ; loose irregular and oblong sponge cells.

SPRUCE SHADE: light 0.0083: diphotophyll 75 μ; epidermis 10 μ; cuticle thin; chlorenchym (55 μ) 1 row funnel and prolobate palisade cells 20 μ; lacunose sponge cells.

Spruce	C. 75 μ	P. 1–2 rows, 45 μ	S. 30 μ
Spruce	C. 55 μ	P. 1 row, 20 μ	S. 35 μ
	—20 μ	—25 μ (55%)	+5 μ (16%)

Light ¼; other factors unchanged except for a probable slight increase in moisture due to deeper shade.

Gravel slide: light 1; available water 2.5–5.5%; humidity 30–65%; temperature 55°–76°: diphotophyll 225 μ; upper cuticle 2–3 μ; chlorenchym (190 μ) 2 compact rows prolate and prolobate palisade cells 40 μ, and a transition row between palisade and sponge; irregular closer sponge cells.

Spruce ...	C. 75 μ	P. 1–2 rows, 45 μ	S. 30 μ
Gravel	C. 190 μ	P. 2 rows, 80 μ	S. 110 μ
	+115 μ	+35 μ (80%)	+80 μ (266%)

Light 33/1; water —(9.5–10.5%); humidity —(4–10%); temperature + (4°–7°).

Fragaria bracteata

Spruce shade: light 0.03; available water 12–16%; humidity 40–70%; temperature 48°–72°: diphotophyll 90 μ; epidermis wavy, upper 20 μ, lower 10 μ; cuticle thin; chlorenchym (60 μ) 1 close row funnel palisade cells 25 μ, and a second shorter scattered row 15 μ; loose oblate sponge cells.

Spruce shade: light 0.1; available water 8–10%: diphotophyll 125 μ; epidermis 20 μ; chlorenchym (85 μ) 2 compact rows narrow prolate palisade cells 25 μ; globose sponge cells.

Spruce	C. 60 μ	P. 2 rows, 40 μ	S. 20 μ
Spruce	C. 85 μ	P. 2 rows, 50 μ	S. 35 μ
	+25 μ	+10 μ (25%)	+15 μ (75%)

Light 3/1; water —(4–6%); probably a little warmer and less humid, but exact amounts unknown.

Thicket shade: light 0.014; available water 19%: diphotophyll 125 μ; epidermis, upper 25 μ, lower 20 μ; chlorenchym (80 μ) 1 loose row funnel palisade cells 30 μ; lacunose oblate sponge cells.

Spruce	C. 60 μ	P. 2 rows, 40 μ	S. 20 μ
Thicket	C. 80 μ	P. 1 row, 30 μ	S. 50 μ
	+20 μ	—1 row, —10 μ (25%)	+30 μ (150%)

Light ½; water + (3–7%); other factors practically the same.

Awning shade (seedling): light 0.0016: diphotophyll 100 μ;

chlorenchym (65 μ) 1 loose row broad funnel palisade cells 25 μ; oblate lacunose sponge cells.

Spruce	C. 60 μ	P. 2 rows, 40 μ	S. 20 μ
Awning	C. 65 μ	P. 1 row, 25 μ	S. 40 μ
	+ 5 μ	— 1 row, — 15 μ (38%)	+ 20 μ (100%)

Light 1/20; moisture probably greater on account of the deep shade, but unmeasured.

Galium triflorum

Spruce shade: light 0.03; available water 12–16%; humidity 40–70%; temperature 48°–72°: diphotophyll 165 μ; epidermis, upper 30 μ, lower 15–25 μ, with enlarged cells; cuticle thin, chlorenchym (115 μ) 1 row funnel palisade cells 50 μ; irregular to oblate sponge cells. (Plate VI, fig. 2 *a*.)

Shady brook bank: light 0.011; available water 18–20%; humidity 60–85%; temperature 47°–69°: diphotophyll 125 μ; epidermis, upper 25 μ, lower 20 μ; chlorenchym (80 μ) 1 row broad-based funnel palisade cells 25 μ; lacunose oblate sponge cells. (Plate VI, fig. 2 *b*.)

Spruce	C. 115 μ	P. 1 row, 50 μ	S. 65 μ
Brook bank ...	C. 80 μ	P. 1 row, 25 μ	S. 55 μ
	— 35 μ	— 25 μ (50%)	— 10 μ (15%)

Light 1/3; water + (4–6%); humidity + (15–20%); temperature — (1°–3°).

Geranium richardsonii

Spruce shade: light 0.03; available water 12–16%; humidity 40–70%; temperature 48°–72°: diphotophyll 160 μ; epidermis, upper 20 μ, lower 15 μ; cuticle thin; chlorenchym (125 μ) 1 loose row prolate palisade cells 60 μ; loose oblate sponge cells. (Plate VI, fig. 3 *a*.)

Sunny brook bank: light 1; available water 40%; humidity 50–70%; temperature 50°–75°: diphotophyll 300 μ; epidermis, upper 35 μ, lower 20 μ; cuticle 3 μ; chlorenchym (250 μ) 2 loose rows of prolate palisade cells, first row 75 μ, second row oblobate cells 65 μ; loose irregular and oblate sponge cells. (Plate VI, fig. 3 *b*.)

Spruce	C. 125 μ	P. 1 row, 60 μ	S. 65 μ
Brook bank	C. 250 μ	P. 2 rows, 140 μ	S. 110 μ
	+ 125 μ	+ 1 row, + 80 μ (133%)	+ 45 μ (69%)

Light 33/1; water + (24–28%); humidity + (0–10%); temperature + (2°–3°).

Thalictrum sparsiflorum

Spruce shade: light 0.03; available water 12–16%; humidity 40–70%; temperature 48°–72°: diphotophyll 125 μ; epidermis wavy, upper 25 μ, lower 15–25 μ; cuticle 2 μ; chlorenchym (80 μ) 1 close row prolate palisade cells 30 μ; loose subglobose to oblate sponge cells.

Shady brook bank: light 0.011; available water 18–20%; humidity 60–85%; temperature 47°–69°: diphotophyll 75 μ; epidermis 15 μ with funnel shaped cells; cuticle thin; chlorenchym (45 μ) 1 loose row funnel palisade cells 25 μ; loose oblate sponge cells.

Spruce	C. 80 μ	P. 1 row, 30 μ	S. 50 μ
Brook bank	C. 45 μ	P. 1 row, 25 μ	S. 20 μ
	— 35 μ	— 5 μ (17%)	— 30 μ (60%)

Light 1/3; water + (4–6%); humidity + (15–20%); temperature — (1°–3°).

Awning shade (seedling): light 0.0016: diphotophyll 75 μ; epidermis 20 μ; with globose cells; cuticle thin; chlorenchym (35 μ) 1 loose row globose to funnel palisade cells 20 μ; oblate sponge cells.

Spruce	C. 80 μ	P. 1 row, 30 μ	S. 50 μ
Awning	C. 35 μ	P. 1 row, 20 μ	S. 15 μ
	— 45 μ	— 10 μ (33%)	— 35 μ (70%)

Light 1/20; other factors practically the same except for a slight probable increase in moisture due to the deeper shade.

Gravel slide: light 1; available water 2.5–5.5%; humidity 30–65%; temperature 55°–76°: diphotophyll 140 μ; epidermis, upper 25 μ with funnel shaped cells, lower 15 μ; cuticle 2 μ; chlorenchym (100 μ) 1 close row prolate palisade cells 50 μ; loose irregular sponge cells.

Spruce	C. 80 μ	P. 1 row, 30 μ	S. 50 μ
Gravel	C. 100 μ	P. 1 row, 50 μ	S. 50 μ
	+ 20 μ	+ 20 μ	0

Light 33/1; water —(9.5–10.5%); humidity —(5–10%); temperature + (4°–7°).

Senecio pudicus

SPRUCE SHADE: light 0.03; available water 12–16%; humidity 40–70%; temperature 48°–72°: diphotophyll 300 μ; epidermis, 35 μ; cuticle, upper 4 μ, lower 2 μ; chlorenchym (230 μ) 1 close row prolate palisade cells 75 μ, and 1 irregular row 50–75 μ; close star-shaped sponge cells.

HALF GRAVEL: light 1; available water 4.5–7.5%; humidity 30–65%; temperature 51°–76°: diphotophyll 385 μ; cuticle, upper 5 μ, lower 3 μ; chlorenchym (310 μ) 2 compact rows prolate palisade cells 75 μ, the second row also oblobate; close irregular or star-shaped sponge cells.

Spruce	C. 230 μ	P. 2 rows, 135 μ	S. 95 μ
Half gravel .	C. 310 μ	P. 2 rows, 150 μ	S. 160 μ
	+80 μ	+15 μ (11%)	+65 μ (68%)

Light 33/1; water — (7.5–8.5%); humidity — (5–10%); temperature + (3°–4°).

Polemonium pulchellum

SPRUCE SHADE: light 0.03; available water 12–16%; humidity 40–60%; temperature 30°–55°: diphotophyll 150 μ, lower surface wavy; epidermis wavy, upper 25 μ, lower 15 μ; cuticle thin; chlorenchym (100 μ) 1 loose row funnel palisade cells 40 μ; lacunose oblate sponge cells. (Plate VI, fig. 4 *a*.)

SPRUCE SHADE: light 0.008: diphotophyll 150 μ, surfaces wavy; chlorenchym (100 μ) very loose row of broad funnel palisade cells 40 μ; lacunose oblate sponge cells.

Spruce	C. 100 μ	P. 1 row, 40 μ	S. 60 μ
Spruce	C. 100 μ	P. 1 row, 40 μ	S. 60 μ
	0	0	0

Light 1/4; other factors the same.

ALPINE GRAVEL: light 1; available water 2.5–5.5%; humidity 40–55%; temperature 40°–65°: diphotophyll 200 μ; epidermis flat, 25 μ; cuticle 2 μ; chlorenchym (150 μ) 2 compact rows prolate palisade cells, the first row 60 μ, the second row 50 μ, (both 100 μ); compact globose sponge cells with indications of a layer of prolate cells next to lower epidermis, which crowds and flattens normal sponge cells. (Plate VI, fig. 4 *b*.)

Spruce	C. 100 μ	P. 1 row, 40 μ	S. 60 μ
Gravel	C. 150 μ	P. 2 rows, 100 μ	S. 50 μ
	+50 μ	+1 row, +60 μ (150%)	−10 μ (17%)

Light 33/1; water — 10%; humidity — (0–15%) temperature — 10°.

Draba streptocarpa

ALPINE SPRUCE SHADE: light 0.03; available water 12–16%; humidity 40–60%; temperature 30°–55°: diphotophyll 300 μ; epidermis 25 μ; cuticle 4 μ; chlorenchym (250 μ) 2–3 close rows prolate palisade cells 40–60 μ; close subglobose sponge cells.

ALPINE MEADOW: light 1; available water 12–17%; humidity 40–55%; temperature 40°–60°: diphotophyll 400 μ; chlorenchym (350 μ) 3–4 close rows subglobose to prolate palisade cells 50 μ; close subglobose sponge cells.

Spruce	C. 250 μ	P. 2–3 rows, 125 μ	S. 125 μ
Meadow	C. 350 μ	P. 3–4 rows, 175 μ	S. 175 μ
	+ 100 μ	+ 1 row, + 50 μ (40%)	+ 50 μ (40%)

Light 33/1; water the same; humidity —(0–5%); temperature + 10°.

Pseudocymopterus tenuifolius

SPRUCE SHADE: light 0.03; available water 12–16%; humidity 40–70%; temperature 48°–72°: diphotophyll 210 μ; epidermis 25 μ; cuticle thin; chlorenchym (160 μ) 2 compact rows prolate palisade cells 50 μ; compact globose and oblate sponge cells with central region of larger clear cells.

SHADY BROOK BANK: light 0.011; available water 18–20%; humidity 60–85%; temperature 47°–69°: diphotophyll 200 μ; chlorenchym (150 μ) 2 loose rows prolate palisade cells, the first row 60 μ, the second 40 μ, looser and sometimes lacking; globose and oblate sponge cells with central large clear cells.

Spruce	C. 160 μ	P. 2 rows, 100 μ	S. 60 μ
Brook bank .	C. 150 μ	P. 2 rows, 100 μ	S. 50 μ
	— 10 μ	0	— 10 μ (16%)

Light 1/3; water + (4–6%); humidity + (15–20%); temperature —(1°–3°).

HALF GRAVEL: light 1; available water 4.5–7.5%; humidity 30–65%; temperature 51°–76°: diphotophyll 225 μ; epidermis, upper 25–40 μ, lower 25 μ; cuticle 3 μ; chlorenchym (175 μ) 2 compact rows narrow prolate palisade cells, first 75 μ, second 50 μ; compact globose sponge cells.

Spruce	C. 160 μ	P. 2 rows, 100 μ	S. 60 μ
Half gravel .	C. 175 μ	P. 2 rows, 125 μ	S. 50 μ
	+ 15 μ	+ 25 μ (25%)	— 10 μ (16%)

Light 33/1; water — 8%; humidity —(5–10%); temperature +(3°–4°).

Heracleum lanatum

SHADY BROOK BANK: light 0.016; available water 25–30%; humidity 60–85%; temperature 47°–69°: diphotophyll 100 μ; epidermis, upper 20 μ, lower 10 μ; cuticle thin; chlorenchym (70 μ) 1 loose row of funnel palisade cells 35 μ; loose oblate sponge cells.

OPEN SPRUCE: light 1; available water 12–16%; humidity 40–70%; temperature 48°–72°: diphotophyll 150 μ; epidermis, upper 25 μ, lower 15 μ; chlorenchym (110 μ) 1 loose row of prolate palisade cells 60 μ; loose oblate sponge cells.

Shade	C. 70 μ	P. 1 row, 35 μ	S. 35 μ
Sun	C. 110 μ	P. 1 row, 60 μ	S. 50 μ
	+ 40 μ	+ 25 μ (71%)	+ 15 μ (43%)

Light 65/1; water —(13–14%); humidity —(15–20%); temperature +(1°–3°).

Rudbeckia laciniata

SHADY BROOK BANK: light 0.012; available water 15–20%; humidity 60–85%; temperature 47°–69°: diphotophyll 160 μ; lower epidermis 15 μ; cuticle 2 μ; chlorenchym (120 μ) 1 lacunose row prolate palisade cells, 60 μ; lacunose oblate sponge cells. (Plate VI, fig. 6 *a*.)

ASPEN CLEARING: light 1; humidity 30–65%; temperature 51°–76°: diphotophyll 275 μ; epidermis 25 μ; cuticle 4 μ; chlorenchym (225 μ) 1 compact row prolate palisade cells, 75 μ, and a lacunose row, 50 μ; lacunose triangular sponge cells. (Plate VI, fig. 6 *b*.)

Brook bank	C. 120 μ	P. 1 row, 60 μ	S. 60 μ
Aspens	C. 225 μ	P. 2 rows, 125 μ	S. 100 μ
	+ 105 μ	+ 1 row, + 65 μ (108%)	+ 40 μ (66%)

Light 80/1; water the same; humidity —(20–30%); temperature —(3°–4°).

Primula parryi

ALPINE ROCK CLEFT: light 0.05; available water 12–17%; humidity 40–60%; temperature 30°–55°: diphotophyll 350 μ; epidermis, upper 25 μ with raised stomata, lower 20 μ; cuticle thin;

chlorenchym (305 μ) 1 lacunose row prolate palisade cells, 60 μ; lacunose sponge cells, closer next to palisade. (Plate VII, fig. 1 *a*.)

Sunny brook bank: light 1; available water 15–25%; humidity 50–70%; temperature 50°–75°: diphotophyll 375 μ; chlorenchym (330 μ) 2 lacunose rows prolate palisade cells 75 μ; lacunose sponge cells. (Plate VII, fig. 1 *b*.)

Rock cleft .	C. 305 μ	P. 1 row, 60 μ	S. 245 μ
Brook bank	C. 330 μ	P. 2 rows, 150 μ	S. 180 μ
	+25 μ	+1 row, +90 μ (150%)	−65 μ (26%)

Light 20/1; water +(3–8%); humidity +10%; temperature +20°.

Opulaster intermedia

Half gravel: light 0.1; available water 10%; humidity 30–65%; temperature 57°–76°: diphotophyll 175 μ; epidermis, upper 30 μ, lower 25 μ; cuticle, upper 3 μ, lower 2 μ; chlorenchym (120 μ) 1 close row prolate palisade cells 40 μ; loose irregular sponge cells.

Thicket shade: light 0.014; available water 19%; humidity 40–70%; temperature 48°–72°: diphotophyll 125 μ with lower surface undulating; cuticle thin; lower epidermis 15 μ with numerous inverted funnel cells (50 μ) chlorenchym (80 μ) 1 loose row tapering palisade cells 30 μ; lacunose oblate sponge cells.

Half gravel	C. 120 μ	P. 1 row, 40 μ	S. 80 μ
Thicket	C. 80 μ	P. 1 row, 30 μ	S. 50 μ
	−40 μ	−10 μ (25%)	−30 μ (37%)

Light 1/7; water +9%; humidity +(5–10%); temperature —(3°–4°).

HELIOPHYTA

Gentiana acuta

Open aspens: light 0.8; available water 9–14%; humidity 30–65%; temperature 50°–75°: diphotophyll 250 μ; epidermis, upper 30 μ with cuticle 3 μ and frequent papillae, lower 20 μ with thin cuticle and no papillae; chlorenchym (200 μ) 2 close rows subglobose and prolate palisade cells 40 μ; loose globose to oblong sponge cells.

Spruce shade: light 0.03; available water 12–16%; humidity 40–70%; temperature 48°–72°: diphotophyll 125 μ; epidermis, upper 25 μ with cuticle 2 μ; chlorenchym (80 μ) 1 close row subglobose palisade cells 25 μ; loose globose to oblong sponge cells.

Aspens	C. 200 μ	P. 2 rows, 80 μ	S. 120 μ
Spruce	C. 80 μ	P. 1 row, 25 μ	S. 55 μ
	— 120 μ	— 1 row, — 55 μ (69%)	— 65 μ (54%)

Light 1/27; water +(2–3%); humidity +(5–10%); temperature —(2°–3°).

ALPINE MEADOW (dwarf): light 1; available water 12–17%; humidity 40–55%; temperature 40°–65°: diphotophyll 175 μ; chlorenchym (130 μ) 1 close row globose to prolate and oblate palisade cells, and 1 looser row 30 μ; loose oblong sponge cells.

Aspens	C. 200 μ	P. 2 rows, 80 μ	S. 120 μ
Meadow	C. 130 μ	P. 2 rows, 60 μ	S. 70 μ
	— 70 μ	— 20 μ (25%)	— 50 μ (42%)

Light 1¼; water + 3%; humidity —(0–15%); temperature — 10°.

Chamaenerium angustifolium

ASPENS: light 0.8; available water 9–14%; humidity 30–65%; temperature 50°–75°: diphotophyll 250 μ; epidermis 15 μ; cuticle 2 μ; chlorenchym (220 μ) 2 compact rows prolate palisade cells, first row 75 μ; second row 50 μ, looser; close triangular and globose sponge cells, the lower ones prolate and oblobate. (Plate VI, fig. 5 *a*.)

HALF GRAVEL: light 1; available water 4.5–7.5%; temperature 51°–76°: differs from type only in more compact sponge.

Light 1¼; water —(4.5–6.5%); humidity the same; temperature + 1°.

GRAVELLY BROOK BANK: light 1; available water 8%; temperature 55°–76°: similar to type.

Light 1¼; water —(1–6%); humidity the same; temperature +(1°–5°).

ALPINE GRAVEL: light 1; available water 2.5–5.5%; humidity 30–50%; temperature 40°–65°: diphotophyll 230 μ; chlorenchym 200 μ; palisade cells 50 μ; compact globose sponge cells.

Aspens	C. 220 μ	P. 2 rows, 125 μ	S. 95 μ
Gravel	C. 200 μ	P. 2 rows, 100 μ	S. 100 μ
	— 20 μ	— 25 μ (20%)	+ 5 μ (5%)

Light 1¼; water —(6.5–8.5%); humidity —(0–15%); temperature — 10°.

SUBALPINE BOG: light 1; available water 58%; humidity 50–

70%: diphotophyll 200 μ; second row of palisade lacunose and oblobate; loose oblate sponge cells.

Light 1¼; water +(44–49%); humidity +(5–20%); temperature the same.

ALPINE ROCK-CLEFT: light 0.05; available water 12–17%; humidity 40–60%; temperature 40°–65°: diphotophyll 200 μ; upper epidermis 20 μ with longer cells; chlorenchym (165 μ) first row of palisade 60 μ, second row 40 μ, reduced or lacking; loose irregular sponge cells. (Plate VI, fig. 5 *b*.)

Aspens	C. 220 μ	P. 2 rows, 125 μ	S. 95 μ
Rock-cleft ...	C. 165 μ	P. 2 rows, 100 μ	S. 65 μ
	— 55 μ	— 25 μ (20%)	— 30 μ (31%)

Light 1/17; water + 3%; humidity —(0–10%); temperature — 10°.

SUBALPINE THICKET: light 0.01; available water 19%; humidity 40–70%; temperature 48°–72°: diphotophyll 125 μ; epidermal cells elongated; cuticle thin; chlorenchym (100 μ) 1 loose row funnel palisade cells 35 μ, and a row of globose cells, the remains of the second row of palisade 25 μ; loose oblate sponge cells. (Plate VI, fig. 5 *c*.)

Aspens	C. 220 μ	P. 2 rows, 125 μ	S. 95 μ
Thicket	C. 100 μ	P. 2 rows, 60 μ	S. 65 μ
	— 120 μ	— 65 μ (52%)	— 30 μ (31%)

Light 1/80; water +(5–10%); humidity +(5–10%); temperature —(2°–3°).

ALPINE SPRUCE THICKET (seedling): light 0.0028; available water 12–16%; humidity 40–60%; temperature 30°–55°: diphotophyll 75 μ; epidermis 10 μ; cuticle thin; chlorenchym (55 μ) 2 loose rows funnel palisade cells (20 μ) second row looser; a row or so of tiny globose and oblate sponge cells. (Plate VI, fig. 5 *d*.)

Aspens	C. 220 μ	P. 2 rows, 125 μ	S. 95 μ
Spruce	C. 55 μ	P. 2 rows, 40 μ	S. 15 μ
	— 165 μ	— 85 μ (68%)	— 80 μ (84%)

Light 1/300; water +(2–3%); humidity —(0–10%); temperature — 20°.

Mertensia polyphylla

SUNNY BROOK BANK: light 1; available water 15–25%; humidity

50–70%; temperature 50°–75°: diphotophyll 250 μ; epidermis, upper 25 μ, lower 20 μ; cuticle 2 μ; chlorenchym (205 μ) 1 lacunose row prolate palisade cells 60 μ; lacunose oblate sponge cells. (Plate VII, fig. 2 *a*.)

BIRCH THICKET: light 0.03; available water 18%; humidity 40–70%; temperature 48°–72°: diphotophyll 175 μ; epidermis, upper 20 μ, flattened, lower 15 μ; cuticle thin; chlorenchym (140 μ) 1 lacunose row prolate palisade cells 50 μ; lacunose oblate sponge cells.

Brook bank ...	C. 205 μ	P. 1 row, 60 μ	S. 145 μ
Thicket	C. 140 μ	P. 1 row, 50 μ	S. 90 μ
	—65 μ	—10 μ (17%)	—55 μ (38%)

Light 1/33; water —2%; humidity —(0–10%); temperature —(2°–3°).

ALPINE MEADOW: light 1; available water 12–17%; humidity 40–55%; temperature 40°–65°: diphotophyll 250 μ; cuticle, upper 4 μ, lower 2 μ; chlorenchym (205 μ) 1 close row prolate palisade cells 70 μ; loose oblate sponge cells. (Plate VII, fig. 2 *b*.)

Brook bank ...	C. 205 μ	P. 1 row, 60 μ	S. 145 μ
Meadow	C. 205 μ	P. 1 row, 70 μ	S. 135 μ
	0	+10 μ (17%)	—10 μ (7%)

Light 1; water —(3–8%); humidity —(10–15%); temperature — 10°.

GRAVELLY BROOK BANK: light 1; available water 8%; temperature 55°–76°: diphotophyll 250 μ; chlorenchym (205 μ) 1 loose row prolate palisade cells 60 μ; close oblate sponge cells.

Brook bank	C. 205 μ	P. 1 row, 60 μ	S. 145 μ
Gravel	C. 205 μ	P. 1 row, 60 μ	S. 145 μ
	0	0	0

Light 1; water —(7–17%); humidity the same; temperature +(1°–5°).

Aconitum columbianum

SUNNY BROOK BANK: light 1; available water 15–25%; humidity 50–70%; temperature 50°–75°: diphotophyll 300 μ; epidermis 25 μ; cuticle 2 μ; chlorenchym (250 μ) 1 close row prolate palisade cells 75 μ (one-fourth to one-fifth prolobate); lacunose irregular elongated sponge cells. (Plate VII, fig. 3 *a*.)

SHADY BROOK BANK: light 0.016; available water 25–30%; humidity 60–85%; temperature 47°–69°: diphotophyll 200 μ; epidermis, upper 20–40 μ, wavy, lower 15–20 μ; cuticle thin; chlorenchym (150 μ) 1 loose row funnel palisade cells (the majority prolobate); very lacunose oblate sponge cells. (Plate VII, fig. 3 *b*.)

Sunlight	C. 250 μ	P. 1 row, 75 μ	S. 175 μ
Shade	C. 150 μ	P. 1 row, 45 μ	S. 105 μ
	— 100 μ	— 30 μ (40%)	— 70 μ (40%)

Light 1/65; water +(5–10%); humidity +(10–15%); temperature —(3°–6°).

Swertia scopulina

SUNNY BROOK BANK: light 1; available water 15–25%; humidity 50–70%; temperature 50°–75°: diphotophyll 250 μ; epidermis, upper 30 μ, lower 25 μ; cuticle 3 μ; chlorenchym (195 μ) 1–2 rows subglobose, prolate and prolobate palisade cells 30 μ; lacunose oblong sponge cells.

ALPINE MEADOW (dwarf): light 1; available water 12–17%; humidity 40–55%; temperature 40°–65°: diphotophyll 350 μ; cuticle 5 μ; chlorenchym (295 μ) 3–4 rows closer palisade cells; loose irregular and oblong sponge cells.

Brook bank	C. 195 μ	P. 2 rows, 60 μ	S. 135 μ
Meadow ...	C. 295 μ	P. 4 rows, 140 μ	S. 155 μ
	+ 100 μ	+ 2 rows, + 80 μ (133%)	+ 20 μ (15%)

Light 1; water —(3–8%); humidity —(5–10%); temperature — 10°.

Polygonum bistortoides

SUNNY BROOK BANK: light 1; water-content 15–25%; humidity 50–70%; temperature 50°–75°: staurophyll 275 μ; epidermis 25 μ; cuticle 3 μ; chlorenchym (225 μ) loose chains of prolate palisade cells extending across the leaf, looser in lower half 25–50 μ.

ALPINE GRAVEL (dwarf): light 1; available water 2.5–5.5%; humidity 30–50%; temperature 40°–65°: similar to type except that tissues are compact instead of loose.

Light 1; water —(12.5–19.5%); humidity — 20%; temperature — 10°.

Sieversia turbinata

ALPINE MEADOW: light 1; available water 12–17%; humidity 40–55%; temperature 40°–65°: diphotophyll 275 μ; epidermis 25 μ;

cuticle 2 μ; chlorenchym (225 μ) 2 close rows prolate palisade cells 75 μ; close subglobose to oblate sponge cells.

ALPINE SPRUCE: light 0.03; humidity 40–60%; temperature 30°–55°: diphotophyll 160 μ; epidermis 10 μ; cuticle thin; chlorenchym (140 μ); 2 loose rows prolate palisade cells 35 μ; loose globose sponge cells.

Meadow	C. 225 μ	P. 2 rows, 150 μ	S. 75 μ
Spruce	C. 140 μ	P. 2 rows, 70 μ	S. 70 μ
	—85 μ	—80 μ (53%)	—5 μ (6%)

Light 1/33; water the same; humidity +(0–5%); temperature — 10°.

Ranunculus inamoenus

SUBALPINE WET MEADOW: light 1; available water 20–30%; humidity 40–70%; temperature 50°–75°: diphotophyll 225 μ; epidermis, upper 25 μ, lower 20 μ; cuticle 2 μ; chlorenchym (180 μ) 2 close irregular rows prolate palisade cells 45 μ; close oblate sponge cells.

ALPINE MEADOW: light 1; available water 12–17%; humidity 40–55%; temperature 40°–65°: diphotophyll 375 μ; chlorenchym (325 μ) 2–3 close rows prolate palisade cells 50 μ; close irregular sponge cells.

Subalpine ..	C. 180 μ	P. 2 rows, 90 μ	S. 90 μ
Alpine	C. 325 μ	P. 3 rows, 150 μ	S. 175 μ
	+145 μ	+1 row, +60 μ (66%)	+85 μ (94%)

Light 1; water —(8–13%); humidity —(0–15%); temperature — 10°.

Saxifraga interrupta

SUBALPINE MEADOW: light 1; available water 12–16%; humidity 40–70%; temperature 50°–75°: diphotophyll 800 μ in center, 300 μ at edges; epidermis, upper 25 μ, lower 20 μ; cuticle 2 μ; chlorenchym (755 μ in center, 255 μ at edges) 3–4 close rather regular rows prolate palisade cells 50 μ; and a region of close subglobose cells; subglobose to oblong lacunose sponge cells.

ALPINE MEADOW: light 1; humidity 40–55%; temperature 40°–65°: no variation from the type.

Light 1; water the same; humidity —(0–15%); temperature — 10°.

ALPINE SPRUCE: light 0.033; humidity 40–55%; temperature 40°–65°: no variation from the type.

Light 1/33; water the same; humidity —(0–15%); temperature — 10°.

Rydbergia grandiflora

ALPINE MEADOW: light 1; available water 12–17%; humidity 30–50%; temperature 40°–65°: staurophyll 775 μ; epidermis 25 μ; cuticle 8 μ; chlorenchym (725 μ) loose prolate cells 60–100 μ.

ALPINE SPRUCE: light 0.03: chlorenchym lacunose.

The leaf of the shade-form is much larger than that of the sun-plant, and hence relatively much thinner. The loose arrangement of the cells in the sun-leaf is due to the shading effect of the woolly covering of hairs on the leaf. The only change in the shade-leaf is a still looser arrangement of the cells.

Quercus novimexicana

HALF GRAVEL NEAR BROOK BANK: light 1; available water 16%; humidity 30–65%; temperature 51°–76°: diphotophyll 200 μ; epidermis, upper 25 μ, lower 10 μ; cuticle 2 μ; chlorenchym (165 μ) 1 compact row prolate palisade cells 50 μ, and a shorter scattered row 35 μ; loose irregular and prolate sponge cells. (Plate VII, fig. 4 *a*.)

THICKET: light 0.06; humidity 40–70%; temperature 48°–72°: diphotophyll 125 μ; epidermis, upper 15 μ; cuticle thin; chlorenchym (100 μ) 1 close row prolate palisade cells 35 μ, and the remains of a second row 25 μ; loose irregular sponge cells. (Plate VII, fig. 4 *b*.)

Half gravel ..	C. 165 μ	P. 2 rows, 85 μ	S. 80 μ
Thicket	C. 100 μ	P. 2 rows, 60 μ	S. 40 μ
	—65 μ	—25 μ (29%)	—20 μ (25%)

Light 1/16; water the same; humidity +(5–10%); temperature —(3°–4°).

Valeriana acutiloba

MEADOW: light 1; available water 9–14%; humidity 30–65%; temperature 50°–75°: diphotophyll 400 μ; epidermis, upper 25 μ, lower 15 μ; cuticle 2 μ; chlorenchym (360 μ) 3–4 loose irregular rows globose to prolate palisade cells 30–50 μ; close subglobose and oblate sponge cells.

SPRUCE: light 0.03; available water 12–16%; humidity 40–70%;

temperature 48°–72°: diphotophyll 175 μ; epidermis 20 μ; chlorenchym (135 μ) 2 loose rows of subglobose palisade cells 25 μ; loose oblate sponge cells.

Meadow	C. 360 μ	P. 3–4 rows, 180 μ	S. 180 μ
Spruce	C. 135 μ	P. 2 rows, 50 μ	S. 85 μ
	—225 μ	—1–2 rows, —130 μ (72%)	—95 μ (52%)

Light 1/33; water +(2–3%); humidity +(5–10%); temperature —(2°–3°).

Prunus demissa

HALF GRAVEL: light 1; available water 10%; humidity 30–65%; temperature 51°–76°: diphotophyll 220 μ; epidermis, upper 25 μ, lower 20 μ; cuticle 3 μ; chlorencym (175 μ) 2 compact rows prolate palisade cells 60 μ; loose irregular sponge cells.

FOOTHILL THICKET: light 0.0125; available water 15%; humidity 38–80%; temperature 53°–85°: diphotophyll 150 μ; cuticle, upper 2 μ, lower thin; chlorenchym (105 μ) 1 compact row prolate palisade cells 40 μ, and the remains of a second row 25 μ; lacunose oblate sponge cells.

Half gravel	C. 175 μ	P. 2 rows, 120 μ	S. 55 μ
Thicket ...	C. 105 μ	P. 1½ rows, 65 μ	S. 40 μ
	—70 μ	—½ row, —55 μ (46%)	—15 μ (27%)

Light 1/80; water + 5%; humidity +(8–15%); temperature +(2°–9°).

Viburnum pauciflorum

GRAVELLY BROOK BANK: light 1; available water 8%; humidity 40–70%; temperature 55°–76°: diphotophyll 225 μ; epidermis 20 μ; cuticle thin, chlorenchym (185 μ) 2 rows prolate and prolobate palisade cells, the first close 50 μ, the second looser 35 μ; loose irregular sponge cells. (Plate VII, fig. 5 *a*.)

THICKET: light 0.014; available water 19%; temperature 48°–72°: diphotophyll 175 μ; epidermis 15 μ; chlorenchym (145 μ) 1 loose row prolobate palisade cells 40 μ; lacunose irregular sponge cells. (Plate VII, fig. 5 *b*.)

Brook bank	C. 185 μ	P. 2 rows, 85 μ	S. 100 μ
Thicket	C. 145 μ	P. 1 row, 40 μ	S. 105 μ
	—40 μ	—1 row, —45 μ (53%)	+5 μ (5%)

Light 1/70; water + 11%; humidity the same; temperature —(4°–7°).

XEROPHYTA

Bursa bursa-pastoris

Half gravel: light 1; available water 4.5–7.5%; humidity 30–65%; temperature 51°–76°: diphotophyll 175 μ; epidermis 20 μ; cuticle 2 μ; chlorenchym (135 μ) 3 compact rows globose to prolate palisade cells 25 μ; close globose to oblate sponge cells.

Brook bank thicket: light 0.011; available water 18–20%; humidity 60–85%; temperature 47°–69°: diphotophyll 225 μ; lower epidermis 10 μ with flattened elongated cells; cuticle thin; chlorenchym (195 μ) 1 loose row broad subglobose and prolate palisade cells 50 μ, and second row of large globose to oblate cells 25 μ; loose oblate sponge cells.

Half gravel	C. 135 μ	P. 3 rows, 75 μ	S. 60 μ
Brook bank	C. 195 μ	P. 2 rows, 75 μ	S. 120 μ
	+ 60 μ	— 1 row, 0	+ 60 μ (100%)

Light 1/100; water + 13%; humidity + (20–30%); temperature —(4°–7°).

Potentilla propinqua

Half gravel: light 1; available water 4.5–7.5%; humidity 30–65%; temperature 51°–76°: diphotophyll 150 μ; epidermis, upper 25 μ, lower 15 μ; cuticle 2 μ; chlorenchym (115 μ) 2 loose rows prolate palisade cells 35 μ; globose sponge cells.

Thicket shade: light 0.06; available water 16%; humidity 40–70%; temperature 48°–72°: diphotophyll 150 μ; cuticle thin; looser palisade; loose oblate sponge cells.

The cuticle is thinner and the chlorenchym tissues looser; otherwise there is no variation from the type.

Light 1/16; water + (8.5–11.5%); humidity + (5–10%); temperature —(3°–4°).

Blitum capitatum

Half gravel: light 0.8; available water 4.5–7.5%; humidity 30–65%; temperature 51°–76°: diphotophyll 275 μ; epidermis, upper 20 μ, lower 15 μ; cuticle thin; chlorenchym (240 μ) 2–3 compact rows prolate palisade cells 50 μ; loose irregular sponge cells. (Plate VII, fig. 6 *a*.)

Brook bank thicket: light 0.011; available water 18–20%; humidity 60–85%, temperature 47°–69°: diphotophyll 100 μ; epi-

dermis 15 μ, upper wavy; chlorenchym (70 μ) 1 loose row funnel palisade cells 35 μ; lacunose oblate sponge cells. (Plate VII, fig. 6 *b*.)

Half gravel	C. 240 μ	P. 2–3 rows, 125 μ	S. 115 μ
Thicket ...	C. 70 μ	P. 1 row, 35 μ	S. 35 μ
	— 170 μ	— (1–2) rows, — 90 μ (72%)	— 80 μ (70%)

Light 1/80; water +13%; humidity +(20–30%); temperature —(4°–7°).

Campanula petiolata

HALF GRAVEL: light 1; available water 4.5–7.5%; humidity 30–65%; temperature 51°–76°: diphotophyll 250 μ; epidermis, upper 25 μ, lower 20 μ; cuticle 5 μ; chlorenchym (205 μ) 2 compact irregular rows prolate palisade cells 50 μ, the lower row more or less indistinct; compact triangular sponge cells, lower ones more or less prolate.

THICKET: light 0.016; available water 13–18%; humidity 40–70%; temperature 48°–72°: diphotophyll 120 μ; epidermis 20 μ with long cells; cuticle thin; chlorenchym (80 μ) 1 loose row prolate palisade cells 25 μ; close oblate sponge cells.

Half gravel	C. 205 μ	P. 2 rows, 100 μ	S. 105 μ
Thicket ...	C. 80 μ	P. 1 row, 25 μ	S. 55 μ
	— 125 μ	— 1 row, — 75 μ (75%)	— 50 μ (47%)

Light 1/65; water +(8.5–10.5%); humidity +(5–10%); temperature —(3°–4°).

Lactuca ludoviciana

HALF GRAVEL: light 1; available water 4.5–7.5%; humidity 30–65%; temperature 51°–76°: diphotophyll 175 μ; epidermis, upper 20 μ, with cuticle 5 μ; lower 25–30 μ, with cuticle 2 μ; chlorenchym (130 μ) 1 compact row prolate and prolobate palisade cells 40 μ; close irregular sponge cells.

THICKET: light 0.016; humidity 40–70%; temperature 48°–72°: the only deviation from the type is the thinner cuticle.

Light 1/65; water the same; humidity +(5–10%); temperature —(3°–4°).

Geranium caespitosum

HALF GRAVEL: light 1; available water 4.5–7.5%; humidity 30–65%; temperature 51°–76°: diphotophyll 350 μ; epidermis 25 μ;

cuticle 2 μ; chlorenchym (300 μ) 2 compact rows prolate palisade cells 75 μ, and a partial third row 50 μ, definite or lacking entirely and usually of oblobate cells; close irregular sponge cells.

THICKET: light 0.13; available water 10–13%; humidity 40–70%; temperature 48°–72°: diphotophyll 175 μ; epidermis 20 μ; cuticle thin; chlorenchym (135 μ) 1 loose row prolate palisade cells 60 μ, and 1 looser row of oblobate cells 40 μ; loose oblate sponge cells.

Half gravel	C. 300 μ	P. 2½ rows,	200 μ	S. 100 μ
Thicket ...	C. 135 μ	P. 1½ rows,	100 μ	S. 35 μ
	— 165 μ	— 1 row,	— 100 μ (50%)	— 65 μ (65%)

Light 1/77; water + 5.5%; humidity +(5–10%); temperature —(3°–4°).

Drymocallis fissa

GRAVEL: light 1; available water 2.5–5.5%; humidity 30–65%; temperature 55°–76°: diphotophyll 185 μ; epidermis, upper 20 μ, lower 15 μ; cuticle 3 μ; chlorenchym (150 μ) 2 compact rows prolate palisade cells 40 μ, and a third looser row 25 μ; loose more or less prolate sponge cells.

SUNNY BROOK BANK: light 1; available water 19%; humidity 50–70%; temperature 50°–75°: diphotophyll 175 μ; chlorenchym (140 μ) 2 loose rows prolate palisade cells 35 μ, a third lacunose or lacking row 15 μ; lacunose subglobose sponge cells.

Gravel	C. 150 μ	P. 3 rows,	105 μ	S. 45 μ
Brook bank	C. 140 μ	P. 2½ rows,	85 μ	S. 55 μ
	— 10 μ	— ½ row,	— 20 μ (19%)	+ 10 μ (22%)

Light 1; water + 15%; humidity +(5–20%); temperature —(1°–5°).

SPRUCE: light 0.03; available water the same; humidity 40–70%; temperature 48°–72°: diphotophyll 105 μ; cuticle thin; chlorenchym (70 μ) 2 close rows prolate palisade cells 20 μ; loose triangular sponge cells.

Gravel	C. 150 μ	P. 3 rows,	105 μ	S. 45 μ
Spruce	C. 70 μ	P. 2 rows,	40 μ	S. 30 μ
	— 80 μ	— 1 row,	— 65 μ (62%)	— 15 μ (33%)

Light 1/33; water the same; humidity +(5–10%); temperature —(4°–7°).

Galium boreale

GRAVEL: light 1; available water 2.5–5.5%; humidity 30–65%; temperature 55°–76°: diphotophyll 250 μ; epidermis, upper 40 μ, lower 30 μ; cuticle 5 μ; chlorenchym (180 μ) 2 close irregular rows prolate palisade cells, first row 50 μ, second row 30–40 μ; close irregular sponge cells. (Plate VIII, fig. 1 *a*.)

SPRUCE SHADE: light 0.03; available water 12–16%; humidity 40–70%; temperature 48°–72°: diphotophyll 125 μ; epidermis 15 μ, slightly wavy, lower surface undulating; cuticle thin; chlorenchym (95 μ) 1 loose row funnel palisade cells 30 μ; loose oblate sponge cells. (Plate VIII, fig. 1 *b*.)

Gravel	C. 180 μ	P. 2 rows, 80 μ	S. 100 μ
Spruce	C. 95 μ	P. 1 row, 30 μ	S. 65 μ
	—85 μ	—1 row, —50 μ (62%)	— 35 μ (35%)

Light 1/33; water + 10%; humidity +(5–10%); temperature —(4°–7°).

AWNING SHADE (seedling): light 0.0016; available water 12–16%; humidity 40–70%; temperature 48°–72°: diphotophyll 100 μ; epidermis 15 μ slightly wavy, lower surface undulating; cuticle thin; chlorenchym (70 μ) 1 lacunose loose row funnel palisade cells 30 μ; very oblate lacunose sponge cells.

Gravel	C. 180 μ	P. 2 rows, 80 μ	S. 100 μ
Awning ...	C. 70 μ	P. 1 row, 30 μ	S. 40 μ
	—110 μ	—1 row, —50 μ (62%)	— 60 μ (60%)

Light 1/600; water + 10%; humidity +(5–10%); temperature —(4°–7°).

Holodiscus dumosa

ROCK: light 1; available water 3%; humidity 30–65%; temperature 51°–76°: diphotophyll 115 μ; epidermis, upper 15 μ, wavy, lower 10 μ; cuticle 2 μ; chlorenchym (90 μ) 2 compact rows prolate palisade cells 25 μ; compact subglobose sponge cells.

SPRUCE SHADE: light 0.03; available water 12–16%; humidity 40–70%; temperature 48°–72°: diphotophyll 65 μ; epidermis, upper 10 μ, lower 5 μ; cuticle thin; chlorenchym (50 μ) 1 loose row funnel and prolate cells, 15 μ, and a second row globose cells 10 μ, looser or lacking; loose oblate sponge cells.

Rock	C. 90 μ	P. 2 rows, 50 μ	S. 40 μ
Spruce	C. 50 μ	P. 1½ rows, 25 μ	S. 25 μ
	—40 μ	—½ row, —25 μ (50%)	—15 μ (37%)

Light 1/33; water +(9–13%); humidity +(5–10%); temperature —(3°–4°).

Pentstemon glaucus

GRAVEL: light 1; available water 2.5–5.5%; humidity 30–65%; temperature 55°–76°: diphotophyll 300 μ; epidermis, upper 25 μ, lower 20 μ; cuticle 3 μ; chlorenchym (255 μ) 3 compact rows prolate palisade cells 50 μ; compact subglobose sponge cells.

ALPINE SPRUCE SHADE: light 0.1; available water 12–16%; humidity 40–60%; temperature 30°–55°: diphotophyll 250 μ; chlorenchym (205 μ) 3 loose rows prolate palisade cells 50 μ; loose subglobose sponge cells.

Gravel	C. 255 μ	P. 3 rows, 150 μ	S. 105 μ
Spruce	C. 205 μ	P. 3 rows, 150 μ	S. 55 μ
	—50 μ	0	—50 μ (47%)

Light 1/10; water + 10%; humidity the same; temperature —(20°–25°).

Symphoricarpus oreophila

GRAVEL: light 1; available water 2.5–5.5%; humidity 28–77%; temperature 57°–89°: diphotophyll 160 μ; epidermis 20 μ; cuticle thin with papillae on upper surface; chlorenchym (120 μ) 1 loose row prolate palisade cells 50 μ, and a second lacunose row 40 μ; loose irregular sponge cells.

BROOK BANK THICKET: light 0.011; available water 18–20%; humidity 60–85%; temperature 47°–69°: diphotophyll 100 μ; chlorenchym (60 μ) 1 lacunose row funnel palisade cells 25 μ; lacunose oblate sponge cells.

Gravel	C. 120 μ	P. 2 rows, 90 μ	S. 30 μ
Thicket	C. 60 μ	P. 1 row, 25 μ	S. 35 μ
	—60 μ	—1 row, —65 μ (72%)	+5 μ (16%)

Light 1/100; water + 15%; humidity +(8–32%); temperature —(10°–20°).

Polygonum convolvulus

FOOTHILL GRAVEL: light 1; available water 2.5–5.5%; humidity 28–77%; temperature 57°–89°: diphotophyll 175 μ; epidermis, upper 25 μ, lower 15 μ; cuticle 2 μ; chlorenchym (125 μ) 1–2 close rows prolate palisade cells, first row 50 μ, second row 25 μ, or one cell replacing two, 75 μ; close subglobose sponge cells. (Plate VIII, fig. 2 *a*.)

BROOK BANK THICKET: light 0.011; available water 18–20%; humidity 60–85%; temperature 47°–69°: diphotophyll 90 μ; cuticle thin; chlorenchym (50 μ) 1 row funnel palisade cells 35 μ; oblate sponge cells. (Plate VIII, fig. 2 *b*.)

Gravel	C. 125 μ	P. 2 rows, 75 μ	S. 50 μ
Thicket	C. 50 μ	P. 1 row, 35 μ	S. 15 μ
	—75 μ	—1 row, —40 μ (53%)	—35 μ (70%)

Light 1/100; water + 15%; humidity +(8–32%); temperature —(10°–20°).

Bidens bigelovii

FOOTHILL HALF GRAVEL: light 1; available water 4.5–7.5%; humidity 28–77%; temperature 57°–89°: diphotophyll 225 μ; epidermis, upper 20–25 μ, lower, 15 μ; cuticle 2 μ; chlorenchym (185 μ) 1 compact row prolate palisade cells 100 μ; compact globose sponge cells. (Plate VIII, fig. 3 *a*.)

FOOTHILL THICKET: light 0.0166; humidity 38–80%; temperature 53°–85°: diphotophyll 50 μ; epidermis, upper 10 μ, wavy, lower 5 μ; cuticle thin; chlorenchym (35 μ) 1 loose row funnel cells 15 μ; loose oblate sponge cells. (Plate VIII, fig. 3 *b*.)

Half gravel ..	C. 185 μ	P. 1 row, 100 μ	S. 85 μ
Thicket	C. 35 μ	P. 1 row, 15 μ	S. 20 μ
	—150 μ	—85 μ (85%)	—65 μ (76%)

Light 1/60; water the same; humidity +(3–10%); temperature —4°.

Capnoides aureum

GRAVEL: light 1; available water 2.5–5.5%; humidity 30–65%; temperature 55°–76°: diphotophyll 200 μ; epidermis, upper 30 μ, lower 25 μ; cuticle thin; chlorenchym (145 μ) 1 close row prolate palisade cells 50 μ; compact oblong sponge cells.

SPRUCE: light 0.03; available water 12–16%; humidity 40–70%; temperature 48°–72°: diphotophyll 100 μ; epidermis 25 μ; chlorenchym (50 μ) 1 row funnel palisade cells 30 μ; loose oblate sponge cells.

Gravel	C. 145 μ	P. 1 row, 50 μ	S. 90 μ
Spruce	C. 50 μ	P. 1 row, 30 μ	S. 20 μ
	—95 μ	—20 μ (40%)	—70 μ (77%)

Light 1/33; water + 10%; humidity +(5–10%); temperature —(4°–7°).

Scutellaria brittonii

GRAVEL: light 1; available water 2.5–5.5%; humidity 30–65%; temperature 55°–76°: diphotophyll 250 μ; epidermis, upper 25 μ, lower 20 μ; cuticle 5 μ; chlorenchym (205 μ) 2–4 close irregular rows prolate palisade cells 25–50 μ; close subglobose sponge cells. (Plate VIII, fig. 4 *a*.)

THICKET: light 0.012; available water 12–15%; humidity 40–70%; temperature 48°–72°: diphotophyll 135 μ; cuticle 2 μ, lower surface undulating; chlorenchym (90 μ) 2 loose irregular rows prolate palisade cells 30 μ; loose subglobose to oblate sponge cells. (Plate VIII, fig. 4 *b*.)

Gravel ..	C. 205 μ	P. 2–4 rows, 105 μ	S. 100 μ
Thicket .	C. 90 μ	P. 2 rows, 60 μ	S. 30 μ
	—115 μ	—1–2 rows, —45 μ (43%)	—70 μ (70%)

Light 1/80; water + 10%; humidity +(5–10%); temperature —(4°–7°).

Therophon jamesii

ALPINE GRAVEL: light 1; available water 2.5–5.5%; humidity 30–50%; temperature 40°–65°: diphotophyll 240 μ; epidermis 20 μ; cuticle 2 μ; chlorenchym (200 μ) 2–3 close rows prolate palisade cells 40 μ; close subglobose sponge cells.

ROCK-CLEFT: light 0.05; available water 8%; humidity 40–60%; temperature 30°–55°: diphotophyll 235 μ; epidermis, upper 40 μ, lower 15 μ; cuticle thin; chlorenchym (175 μ) 1 loose row funnel palisade cells 50 μ, and 1 row subglobose cells 30 μ; loose oblate sponge cells.

Gravel ...	C. 200 μ	P. 2–3 rows, 115 μ	S. 85 μ
Rock-cleft	C. 175 μ	P. 2 rows, 80 μ	S. 95 μ
	—25 μ	—1 row, —35 μ (30%)	+10 μ (12%)

Light 1/20; water + 4%; humidity + 10%; temperature — 10°.

Dasyphora fruticosa

ALPINE GRAVEL: light 1; available water 2.5–5.5%; humidity 30–50%; temperature 40°–65°: diphotophyll 160 μ; epidermis 25 μ; cuticle, upper 3 μ, lower 2 μ; chlorenchym (110 μ) 3 compact rows prolate palisade cells 30 μ; close globose sponge cells.

BOG: light 1; available water 58%; humidity 50–70%; tempera-

ture 50°–75°: diphotophyll 125 μ; chlorenchym (70 μ) 2 loose rows prolate palisade cells 25 μ; lacunose globose sponge cells.

Gravel	C. 110 μ	P. 3 rows, 90 μ	S. 20 μ
Bog	C. 70 μ	P. 2 rows, 50 μ	S. 20 μ
	—40 μ	—1 row, —40 μ (44%)	0

Light 1; water + 54%; humidity + 20%; temperature + 10°.

Atragene acutiloba

GRAVEL: light 1; available water 2.5–5.5%; humidity 30–65%; temperature 55°–76°: diphotophyll 300 μ; epidermis 35 μ; cuticle 2 μ; chlorenchym (230 μ) 1 row compact prolate and prolobate palisade cells 45 μ; compact irregular sponge cells.

SPRUCE: light 0.03; available water 12–16%; humidity 40–70%; temperature 48°–72°: diphotophyll 300 μ; chlorenchym (230 μ) 1 row prolate and prolobate palisade cells 55 μ; close irregular sponge cells.

Gravel	C. 230 μ	P. 1 row, 45 μ	S. 185 μ
Spruce	C. 230 μ	P. 1 row, 55 μ	S. 175 μ
	0	+10 μ (22%)	—10 μ (5%)

Light 1/33; water + 10%; humidity +(5–10%); temperature —(4°–7°).

Apocynum androsaemifolium

GRAVEL: light 1; available water 2.5–5.5%; humidity 30–65%; temperature 55°–76°: diphotophyll 175 μ; epidermis 15 μ, lower surface with papillae; cuticle 2 μ; chlorenchym (145 μ) 1 close row prolate palisade cells 85 μ; close irregular sponge cells. (Plate VIII, fig. 5 *a*.)

THICKET: light 0.016; available water 15–20%; humidity 40–70%; temperature 48°–72°: diphotophyll 100 μ; upper epiderimis irregular, lower with reduced papillae; chlorenchym (70 μ) 1 row funnel palisade cells 30 μ; lacunose oblate sponge cells. (Plate VIII, fig. 5 *b*.)

Gravel	C. 145 μ	P. 1 row, 85 μ	S. 60 μ
Thicket	C. 70 μ	P. 1 row, 30 μ	S. 40 μ
	—75 μ	—55 μ (64%)	—20 μ (33%)

Light 1/80; water +(12.5–14.5%); humidity +(5–10%); temperature —(4°–7°).

Aralia nudicaulis

GRAVEL: light 0.1; available water 2.5–5.5%; humidity 30–65%; temperature 55°–76°: diphotophyll 110 μ; epidermis 10 μ; cuticle thin; chlorenchym (90 μ) 1 close row prolate palisade cells 35 μ; close oblate sponge cells.

THICKET: light 0.014; available water 19%; humidity 40–70%; temperature 48°–72°: diphotophyll 75 μ; epidermis 5–10 μ; chlorenchym (60 μ) 1 loose row funnel palisade cells 25 μ; lacunose oblate sponge cells.

Gravel	C. 90 μ	P. 1 row, 35 μ	S. 55 μ
Thicket	C. 60 μ	P. 1 row, 25 μ	S. 35 μ
	— 30 μ	— 10 μ (28%)	— 20 μ (36%)

Light 1/7; water +(13.5–16.5%); humidity +(5–10%); temperature —(4°–7°).

Artemisia gnaphalodes

FOOTHILL MESA: light 1; available water 2–4%; humidity 28–77%; temperature 57°–89°: diphotophyll 175 μ; epidermis, upper 25 μ, lower 20 μ, lower surface undulating; cuticle, upper 4 μ, lower 2 μ; chlorenchym (130 μ) 1 compact row prolate palisade cells 65 μ; compact globose sponge cells, lower ones prolate.

FOOTHILL THICKET: light 0.0125; available water 11%; humidity 38–80%; temperature 53°–85°: diphotophyll 150 μ; epidermis, upper 20 μ, lower 15 μ, lower surface undulating; cuticle, upper 3 μ, lower thin; chlorenchym (115 μ) 1 close row prolate palisade cells 50 μ; close subglobose sponge cells.

Mesa	C. 130 μ	P. 1 row, 65 μ	S. 65 μ
Thicket	C. 115 μ	P. 1 row, 50 μ	S. 65 μ
	— 15 μ	— 15 μ (23%)	0

Light 1/80; water +(7–9%); humidity +(3–10%); temperature — 4°.

Artemisia ludoviciana

FOOTHILL MESA: light 1; available water 2–4%; humidity 28–77%; temperature 57°–89°: diplophyll 190 μ; surfaces undulating; epidermis, upper 25 μ, lower 15 μ; cuticle, upper 5 μ, lower 2 μ; chlorenchym (150 μ) 1 compact row prolate palisade cells 75 μ next to upper epidermis, and 1 loose row oblobate cells 40 μ next to lower epidermis; central close globose sponge cells. (Plate VIII, fig. 6 *a*.)

THICKET: light 0.0125; available water 11%; humidity 38–80%; temperature 53°–85°: diphotophyll 75 μ; epidermis, upper 15 μ, lower 10 μ; cuticle thin; chlorenchym (45 μ) 1 lacunose row funnel palisade cells 25 μ; lacunose oblate sponge cells. (Plate VIII, fig. 6 *b*.)

Mesa	C. 150 μ	P. 1 row, 75 μ	S. 75 μ
Thicket	C. 45 μ	P. 1 row, 25 μ	S. 20 μ
	— 105 μ	— 50 μ (66%)	— 55 μ (73%)

Light 1/80; water +(7–9%); humidity +(3–10%); temperature — 4°.

Monarda menthifolia

HALF GRAVEL: light 1; available water 4.5–7.5%; humidity 30–65%; temperature 51°–76°: diplophyll 250 μ; epidermis 25 μ; cuticle 4 μ; chlorenchym (200 μ) 1 row prolate palisade cells 100 μ next to upper epidermis, and 1 looser row prolate and oblobate cells 50 μ next to lower epidermis; loose central sponge cells. (Plate VIII, fig. 7 *a*.)

THICKET: light 0.016; available water 15–20%; humidity 40–70%; temperature 48°–72°: diphotophyll 100 μ; epidermis, upper 20 μ, lower 15 μ; lower surface very wavy; cuticle thin; chlorenchym (65 μ) 1 loose row funnel palisade cells 40 μ; lacunose oblate sponge cells. (Plate VIII, fig. 7 *b*.)

Half gravel	C. 200 μ	P. 2 rows,	150 μ	S. 50 μ
Thicket ...	C. 65 μ	P. 1 row,	40 μ	S. 25 μ
	— 135 μ	— 1 row,	— 110 μ (73%)	— 25 μ (50%)

Light 1/65; available water +(10.5–12.5%); humidity +(5–10%); temperature —(3°–4°).

Ximenesia encelioides

FOOTHILL MESA: light 1; available water 2–4%; humidity 28–77%; temperature 57°–89°: diplophyll 325 μ; epidermis, upper 25 μ, lower 15 μ; cuticle thin; chlorenchym (285 μ) 4–5 compact rows prolate cells, uppermost 125 μ, second row 75 μ, lowermost 40 μ; lower and central cells sponge-like.

FOOTHILL THICKET: light 0.0125; available water 11%; humidity 38–80%; temperature 53°–85°: diphotophyll 200 μ; chlorenchym (160 μ) 1 compact row prolate palisade cells 60 μ; close subglobose sponge cells.

Mesa	C. 285 μ	P. 2 rows, 200 μ	S. 85 μ
Thicket ..	C. 160 μ	P. 1 row, 60 μ	S. 100 μ
	— 125 μ	— 1 row, — 140 μ (70%)	+ 15 μ (17%)

Light 1/80; water +(7–9%); humidity +(3–10%); temperature — 4°.

Rudbeckia flava

Half gravel: light 1; available water 4.5–7.5%; humidity 30–65%; temperature 51°–76°: diplophyll 250 μ; epidermis 25 μ; cuticle 3 μ; chlorenchym (200 μ) 2 loose rows prolate palisade cells 50 μ next to upper epidermis, and 1 lacunose row 50 μ next to lower epidermis; central lacunose irregular and prolate cells.

Brook bank thicket: light 0.011; available water 18–20%; humidity 60–85%; temperature 47°–69°: diphotophyll 325 μ; cuticle thin; chlorenchym (275 μ) 1 lacunose row prolate palisade cells 75 μ, a second very scattered row of irregular and oblobate cells; very lacunose star-shaped sponge cells.

Half gravel	C. 200 μ	P. 2 rows, 100 μ	S. 100 μ
Thicket ..	C. 275 μ	P. 1 row, 75 μ	S. 200 μ
	+ 75 μ	— 1 row, — 25 μ (25%)	+ 100 μ (100%)

Light 1/100; water + 13%; humidity +(25–30%); temperature —(4°–7°).

Erigeron speciosus

Gravel: light 1; available water 2.5–5.5%; humidity 30–65%; temperature 55°–76°: diplophyll 250 μ; epidermis 25 μ; cuticle 5 μ; chlorenchym (200 μ) 1–2 loose rows prolate cells next to either epidermis 35–40 μ; central subglobose and oblate cells.

Spruce: light 0.03; available water 12–16%; humidity 40–70%; temperature 48°–72°: no variation from the type.

Light 1/33; water + 10%; humidity +(5–10%); temperature —(4°–7°).

Solidago extraria

Half gravel: light 1; available water 4.5–7.5%; humidity 30–65%; temperature 51°–76°: diplophyll 275 μ; epidermis 30 μ; cuticle 5 μ; chlorenchym (215 μ) 2–3 compact rows prolate cells next to either epidermis 40 μ; central large clear oblate cells.

Thicket: light 0.13; available water 10–13%; humidity 40–70%; temperature 48°–72°: diplophyll 225 μ; chlorenchym (165 μ) cuticle 3 μ; prolate cells 25–40 μ.

The only variation from the type is a slight thinning of the leaf and cuticle under shade conditions.

Light 1/8; water +6%; humidity +(5–10%); temperature —(3°–4°).

Pseudocymopterus anisatus

GRAVEL: light 1; available water 2.5–5.5%; humidity 30–65%; temperature 55°–76°: diplophyll 450 μ; epidermis 40–50 μ; cuticle 10 μ; chlorenchym (350 μ) 3 compact irregular rows prolate cells next to upper epidermis, and 2 next to lower epidermis 60 μ; separated from it by a row of horizontal cells; central water-storage cells.

PINE SHADE: light 0.05; available water 13%; humidity 40–70%; temperature 48°–72°: diplophyll 400 μ; epidermis 50 μ; cuticle 2 μ; chlorenchym (300 μ) cells loosely arranged, third row and lowermost row of prolate cells disappearing.

The cuticle of the shade leaf is thinned, and the palisade tissue is reduced in amount and more loosely arranged.

Light 1/20; water +9%; humidity +(5–10%); temperature —(4°–7°).

Gutierretzia sarothrae

FOOTHILL MESA: light 1; available water 2–4%; humidity 28–77%; temperature 57°–89°: diplophyll 500 μ; epidermis 30 μ; cuticle 10 μ; chlorenchym (440 μ) compact irregular rows prolate palisade cells 50–75 μ, 4 rows next to upper and 3 next to lower epidermis; central water-storage tissue of globose cells.

FOOTHILL THICKET: light 0.0125; available water 11%; humidity 38–80%; temperature 53°–85°: diplophyll 200 μ; epidermis 25 μ; cuticle 5 μ; chlorenchym (150 μ) 3 rows of cells, 25 μ, next to upper and 2 next to lower epidermis; water-storage cells oblate.

The shade-leaf and its cuticle are thinner than for the type; the palisade cells have been reduced in length and in number of rows, and the water-storage cells have changed from globose to oblate in shape.

Light 1/80; water +(7–9%); humidity +(3–10%); temperature —4°.

Euphorbia robusta

FOOTHILL MESA: light 1; available water 2–4%; humidity 28–77%; temperature 57°–89°: diplophyll 250 μ; epidermis 20 μ;

cuticle 5 μ; chlorenchym (210 μ) 1 close row of prolate cells 60 μ next to upper epidermis, and 1 row 40 μ next to lower epidermis; central close subglobose and prolate cells.

FOOTHILL THICKET: light 0.0125; available water 11%; humidity 38–80%; temperature 53°–85°: leaf 225 μ; epidermis 30 μ, wavy; chlorenchym (165 μ) upper cells 50 μ, lower ones 25 μ.

The leaf has become thinner.

Light 1/80; water +(7–9%); humidity +(3–10%); temperature — 4°.

Senecio rosulatus

FOOTHILL GRAVEL: light 1; available water 2.5–5.5%; humidity 28–77%; temperature 57°–89°: diplophyll 325 μ; epidermis 25 μ; cuticle 5 μ; chlorenchym (275 μ) 1 close row of prolate cells 50 μ, next to upper, and 1 looser row 30 μ, next to lower epidermis; central globose and prolate cells.

FOOTHILL ROCK (dwarf): available water 3%, other factors the same: plant dwarfed, leaf small, 275 μ; central cells more prolate.

FOOTHILL SHADE: light 0.0125; available water 11%; humidity 38–80%; temperature 53°–85°: leaf larger 450 μ; upper cells 60 μ, lower ones 40 μ; more loosely arranged.

Light 1/80; water +(7–9%); humidity +(3–10%); temperature — 4°.

Thlaspi coloradense

SUBALPINE GRAVEL: light 1; available water 2.5–5.5%; humidity 30–65%; temperature 51°–76°: staurophyll 500 μ; epiderimis, upper 50 μ, lower 40 μ; cuticle 6 μ; chlorenchym (410 μ) close chains of subglobose and prolate cells 35–75 μ, the longer next to upper epidermis.

ALPINE THICKET: light 0.01; available water 25–30%; humidity 40–60%; temperature 40°–65°: leaf 275 μ; epidermis wavy, upper 40 μ, lower 25 μ; cuticle 3 μ; chlorenchym (210 μ) lacunose chains of subglobose and prolate cells 25–65 μ.

Gravel	C. 410 μ
Thicket	C. 210 μ
	— 200 μ

Light 1/100; water +(22–25%); humidity the same; temperature — 11°.

Boebera papposa

FOOTHILL MESA: light 1; available water 2–4%; humidity 28–77%; temperature 57°–89°: staurophyll 300 μ; epidermis 25–40 μ; cuticle 3 μ; chlorenchym (240 μ) 1 close row prolate palisade cells 85 μ next to upper epidermis, 1 row 60 μ next to lower epidermis; central oblobate cells.

FOOTHILL THICKET: light 0.0125; available water 11%; humidity 38–80%; temperature 53°–85°: diphotophyll 125 μ; epidermis 20 μ; cuticle thin; chlorenchym (85 μ) 1 row prolate palisade cells 35 μ; close globose sponge cells.

Mesa ...	C. 240 μ	P. 4–5 rows,	240 μ	S. 0	staurophyll
Thicket .	C. 85 μ	P. 1 row,	35 μ	S. 50 μ	diphotophyll
	— 155 μ	— 3–4 rows,	— 105 μ (43%)	+ 50 μ	

Light 1/80; water +(7–9%); humidity +(3–10%); temperature — 4°.

Aster torreyi

HALF GRAVEL: light 1; available water 4.5–7.5%; humidity 30–65%; temperature 51°–76°: staurophyll 275 μ; epidermis 20 μ; cuticle 10 μ; chlorenchym (225 μ) loose chains prolate cells 25–40 μ.

SPRUCE SHADE: light 0.03; available water 12–16%; humidity 40–70%; temperature 48°–72°: staurophyll 200 μ; no other difference.

The only variation from the type under shade conditions is a reduction in thickness of leaf.

Light 1/33; water + 8%; humidity +(5–10%); temperature —(3°–4°).

Machaeranthera aspera

GRAVEL: light 1; available water 2.5–5.5%; humidity 30–65%; temperature 55°–76°: staurophyll 250 μ; epidermis 25 μ; cuticle 5 μ; chlorenchym (200 μ) 4 close irregular rows prolate cells interrupted by scattered globose and prolate water-storing cells 40 μ. (Plate VIII, fig. 8 *a*.)

BROOK BANK THICKET: light 0.011; available water 18–20%; humidity 60–85%; temperature 47°–69°: diphotophyll 175 μ; cuticle thin; chlorenchym (125 μ) 1 row prolate cells 40 μ; lacunose oblate sponge cells, and remains of lower prolate cells. (Plate VIII, fig. 8 *b*.)

Gravel ..	C. 200 μ	P. 4 rows,	160 μ	Water cells 40 μ
Thicket .	C. 125 μ	P. 1 row,	40 μ	Sponge 85 μ
	—75 μ	—3 rows,	—120 μ (75%)	

Light 1/100; water + 15%; humidity +(25–30%); temperature —(7°–8°).

Pachylophus caespitosus

FOOTHILL GRAVEL: light 1; available water 2.5–5.5%; humidity 28–77%; temperature 57°–89°: staurophyll 475 μ; epidermis 25–40 μ; cuticle 10 μ; chlorenchym (450 μ) 5–7 irregular overlapping rows prolate cells, first row 100 μ, second 125 μ, third, fourth and fifth 75 μ, sixth and seventh 65 μ; the first row is loose allowing for stomatal air-chambers, the second and third are compact and the last four are loose and oblobate. (Plate IX, fig. 1 *a.*)

FOOTHILL THICKET: light 0.0125; available water 11%; humidity 38–80%; temperature 53°–85°: diphotophyll 350 μ; cuticle 2 μ; chlorenchym (300 μ) 2 lacunose rows prolate palisade cells 75 μ; loose irregular sponge cells. (Plate IX, fig. 1 *b.*)

Gravel	C. 450 μ	P. 7 rows,	450 μ	S. 0
Thicket	C. 300 μ	P. 2 rows,	150 μ	S. 150 μ
	— 150 μ	— 5 rows,	— 300 μ (66%)	+ 150 μ

Light 1/80; water +(7–9%); humidity +(3–10%); temperature — 4°.

Senecio spartioides

GRAVEL: light 1; available water 2.5–5.5%; humidity 30–65%; temperature 55°–76°: staurophyll 450 μ; epidermis, upper 35 μ, lower 25 μ; cuticle, upper 7 μ, lower 2 μ; chlorenchym (390 μ) 7 close irregular rows prolate cells 20–100 μ; central and lower ones oblobate, lowermost and uppermost loose by reason of numerous stomatal air chambers.

THICKET: light 0.016; available water 15–20%; humidity 40–70%; temperature 48°–72°: diphotophyll 375 μ; chlorenchym (315 μ) 2 lacunose rows prolate cells 75 μ; lacunose irregular and prolate sponge cells.

Gravel	C. 390 μ	P. 7 rows,	390 μ	S. 0
Thicket	C. 315 μ	P. 2 rows,	150 μ	S. 165 μ
	—75 μ	— 5 rows,	—240 μ (61%)	+ 165 μ

Light 1/60; water +(12.5–14.5%); humidity +(5–10%); temperature —(4°–7°).

Allionia linearis

GRAVEL: light 1; available water 2.5–5.5%; humidity 30–65%; temperature 55°–76°: staurophyll 680 μ; epidermis 25 μ; upper cuticle 3 μ, lower cuticle 5 μ; chlorenchym (630 μ) 5–6 irregular rows prolate cells, the first row 200 μ, the second and third 125–150 μ, the last two or three rows 50–100 μ, the first three rows compact, the rest looser and oblobate. (Plate IX, fig. 2 *a*.)

FOOTHILL THICKET (tall, flowering form): light 0.0125; available water 11%; humidity 38–80%; temperature 53°–85°: diphotophyll 150 μ; epidermis 15 μ; cuticle thin; chlorenchym (120 μ) 1 row prolate palisade cells 55 μ, and a partial second row; globose sponge cells. (Plate IX, fig. 2 *b*.)

Gravel	C. 630 μ	P. 5 rows, 630 μ	S. 0
Thicket	C. 120 μ	P. 1 row, 55 μ	S. 65 μ
	—510 μ	—4 rows, —575 μ (91%)	+65 μ

Light 1/80; water +(5.5–8.5%); humidity +(8–15%); temperature +(0°–9°).

FOOTHILL THICKET (seedling): light 0.003; other factors like preceding: diphotophyll 110 μ; cuticle thin; chlorenchym (60 μ) 1 row globose and funnel cells 30 μ; globose sponge cells. (Plate IX, fig. 2 *c*.)

Gravel	C. 630 μ	P. 5 rows, 630 μ	S. 0
Thicket	C. 160 μ	P. 1 row, 30 μ	S. 30 μ
	—470 μ	—4 rows, —600 μ (95%)	+30 μ

Light 1/300; water +(5.5–8.5%); humidity +(8–15%); temperature +(0°–9°).

Tall form	C. 120 μ	P. 1 row, 55 μ	S. 65 μ
Seedling	C. 60 μ	P. 1 row, 30 μ	S. 30 μ
	—60 μ	—25 μ (45%)	—35 μ (54%)

Light ¼; other factors the same.

Solanum triflorum

HALF GRAVEL: light 1; available water 4.5–7.5%; humidity 30–65%; temperature 51°–76°: staurophyll 375 μ; epidermis, upper 35 μ, lower 20 μ; cuticle 3 μ; chlorenchym (325 μ) 4 compact rows prolate cells, first row 125 μ, second and third rows 75–100 μ, fourth row 50 μ with looser oblobate cells. (Plate IX, fig. 3 *a*.)

FOOTHILL THICKET: light 0.02; available water 15%; humidity 38–80%; temperature 53°–85°: diphotophyll 250 μ; epidermis 25 μ; cuticle thin; chlorenchym (200 μ) 1 loose row prolate palisade cells 75 μ; loose subglobose and prolate sponge cells. (Plate IX, fig. 3 *b*.)

Half gravel .	C. 325 μ	P. 4 rows, 325 μ	S. 0
Thicket	C. 200 μ	P. 1 row, 75 μ	S. 125 μ
	— 125 μ	— 3 rows, — 250 μ (77%)	+ 125 μ

Light 1/50; water + 9%; humidity +(8–25%); temperature +(2°–9°).

Helianthus pumilus

FOOTHILL HALF GRAVEL: light 1; available water 2.5–5.5%; humidity 28–77%; temperature 57°–89°: staurophyll 425 μ; epidermis 30 μ; cuticle 10 μ; chlorenchym (365 μ) 5–6 loose irregular rows prolate cells 50–75 μ; transverse bands or isolated areas of water-storage tissue of subglobose and polygonal cells. (Plate IX, fig. 4 *a*.)

FOOTHILL THICKET: light 0.0125; available water 15%; humidity 38–80%; temperature 53°–85°: diplophyll 150 μ; epidermis 15 μ; cuticle 2 μ; chlorenchym (120 μ) 4 rows prolate cells 25–50 μ; central ones somewhat irregular. (Plate IX, fig. 4 *b*.)

Half gravel ...	C. 365 μ	P. 5–6 rows, 365 μ	S. 0
Thicket	C. 120 μ	P. 4 rows, 120 μ	S. 0
	— 245 μ	— 1–2 rows, — 245 μ (67%)	0

Light 1/80; water +(9.5–12.5%); humidity +(3–10%); temperature — 4°.

Vagnera stellata

GRAVEL: light 1; available water 2.5–5.5%; humidity 30–65%; temperature 51°–76°: spongophyll 300 μ; epidermis, upper 60 μ, subglobose cells with rudimentary papillae, lower 50 μ, wavy with sunken stomata; cuticle 5 μ; chlorenchym (190 μ) compact globose cells.

THICKET: light 0.022; available water 15%; humidity 40–70%; temperature 48°–72°: spongophyll 250 μ; epidermis, upper 50 μ elongated cells without papillae, lower 30 μ with stomata half sunken; cuticle 3 μ; chlorenchym (170 μ) less compact.

Gravel	C. 190 μ	P. 0	S. 190 μ
Thicket	C. 170 μ	P. 0	S. 170 μ
	— 20 μ	0	— 20 μ (10%)

Light 1/50; water +(9.5–12.5%); humidity +(5–10%); temperature —(3°–4°).

Bog: light 1; available water 58%; humidity 50–70%; temperature 50°–75°: the leaf is like that of the shade form with a thin cuticle.

Light 1; water +(52.5–55.5%); humidity +(5–20%); temperature the same.

VI. Grouping of Polydemic Species

In the following tables the habitat forms of polydemic species are grouped according to the physical factor differences between their habitats and that of the type form. Structural differences in the leaves of the plants themselves are expressed as briefly and as graphically as possible.

Light and Humidity Unchanged; Water Decreased

	Leaf	Cuticle	Palisade			Sponge		
			Amount	Kind	Texture	Amount	Kind	Texture
Mertensia polyphylla	o	o	o	o	closer	o	o	closer
Senecio rosulatus (dwarf)	o	o	o	o	o	o	o	o

Because of the small number of species subjected to the influence of a decrease in available water alone, no general inferences can be drawn. *Mertensia polyphylla* indicates that the effect of decreased water is to be found in the arrangement of the cells alone. The closer position of both the palisade and sponge cells decreases air-spaces, and, in consequence, loss of water by transpiration. In the case of *Senecio rosulatus* the water-supply of the form growing on the rock is at a minimum. The available water for the type form is already small, and the only adaptation to a decrease is a dwarfing of the entire plant.

LIGHT UNCHANGED; WATER AND HUMIDITY DECREASED

	Leaf	Cuticle	Palisade			Sponge		
			Amount	Kind	Texture	Amount	Kind	Texture
Mertensia polyphylla	o	+	+	o	closer	—	o	closer
Swertia scopulina (dwarf)	+	+	+ 2 rows	o	closer	+	o	closer
Polygonum bistortoides (dwarf)	o	o	o	o	closer	o	o	closer
Ranunculus inamoenus	+	o	+ 1 row	o	o	+	less oblate	o

The inference that a decrease in available water tends to a closer arrangement of the chlorenchym cells is here confirmed by the fact that three out of the four species have changed in this way. The decrease in water for the group is accompanied by a decrease in humidity in as much as the compared plant is in each case the alpine form of the species. Since a decrease in humidity tends to increase transpiration, and since the water-supply is reduced, adaptations are in the direction of protection against water loss. Hence intercellular spaces are reduced, and the cuticle may be thickened. The further fact that three out of the four plants have relatively thicker leaves (the dwarf form of *Polygonum* has a leaf as thick but smaller than the type) indicates that dryness tends to increase leaf thickness.

LIGHT UNCHANGED; WATER AND HUMIDITY INCREASED

	Leaf	Cuticle	Palisade			Sponge		
			Amount	Kind	Texture	Amount	Kind	Texture
Chamaenerium angustifolium	—	o	o	prolate to oblobate	looser	—	more oblate	looser
Dasyphora fruticosa	—	o	—1 row	o	looser	o	o	looser
Drymocallis fissa	—	o	—½ row	o	looser	+	less prolate	looser
Vagnera stellata	—	—	o	o	looser	—	o	looser

Conditions of moisture opposed to those for the preceding group obtain for this one, and the converse effects on leaf structure rule. In every case the leaf is thinner and the cells are more loosely arranged. The tension in the leaf on account of surface growth

is indicated in the tendency of the sponge cells to take the oblate shape. These changes must be referred directly to the influence of an increase in humidity and available water, since the light remains the same. They are in the direction of increase in transpiring surface. In *Chamaenerium* the palisade even is influenced in this direction, since the second row is becoming sponge-like.

LIGHT DECREASED; WATER UNCHANGED; HUMIDITY INCREASED

	Leaf	Cuticle	Palisade			Sponge		
			Amount	Kind	Texture	Amount	Kind	Texture
Sparganium angustifolium	—	o	— (2–3) rows	prolate to oblate	o	o	o	o
Acer glabrum	—	o	—	prolate to funnel	o	o	more oblate	o
Edwinia americana	—	—	— 1 row	prolate to funnel	o	+	o	o
Fragaria bracteata	+	o	— 1 row	o	looser	+	o	looser
Thalictrum sparsiflorum (seedling)	—	—	—	prolate to funnel	looser	—	more oblate	o
Polemonium pulchellum	o	o	o	o	looser	o	o	o
Sieversia turbinata	—	—	—	o	looser	—	o	looser
Quercus novimexicana	—	—	—	o	looser	—	less prolate	o
Lactuca ludoviciana	o	—	o	o	o	o	o	o
Saxifraga interrupta	o	o	o	o	o	o	o	o
Rudbeckia laciniata	—	—	— 1 row	o	looser	—	more oblate	o
Bidens bigelovii	—	—	—	prolate to funnel	looser	—	globose to oblate	looser
Drymocallis fissa	—	—	— 1 row	o	looser	—	o	o
Allionia linearis (tall shade form and seedling)	—	o	—	prolate to funnel	o	—	o	o

The conditions for the above group are those of deeper shade, the forms being either shade-forms as compared with sun-forms, or forms growing in differing degrees of shade. In the latter case, the water and humidity for some of the species have not been measured, but the humidity at least is greater the deeper the shade. For these it is possible that the soil-water is somewhat greater as well. The important factor, however, is the decreased light and to it can be referred the main changes in the structure of the leaf.

As is well known, shade-leaves are characteristically large and thin as compared with sun-leaves. With a few exceptions this holds for the group, the reduction in thickness affecting both the palisade and sponge tissues. The increase in the leaf of *Fragaria* may be due to the fact that the leaf is already as thin as is consistent with the proper performance of the physiological functions of the species. The difference between the two deeply shaded forms themselves, the one with one-tenth as much light as the other, is in size of leaf, the extremely shaded plant being able to develop no further than the seedling stage. It is probable that beyond certain limits, changes in physical factors do not produce corresponding changes in the histology of the leaf. This is shown by all of the seedling forms growing in intense shade. The more shaded leaf of *Polemonium* is neither thinner nor thicker, as the light differences are not very great. The palisade cells, however, are more loosely arranged, in response to the decreased light or increased humidity or both, as both have that effect. *Lactuca ludoviciana* and *Saxifraga interrupta* seem to be relatively stable species. The only change in the former is a thinner cuticle, while the latter remains unchanged. The increase in sponge in *Edwinia* may be only apparent since there is no distinct line between the palisade and the sponge tissues, and one had to be arbitrarily drawn for purposes of comparison.

As shown by the table, reduced light, besides decreasing the palisade and sponge tissues in amount, shortens and broadens the palisade cells and extends the sponge cells in a horizontal direction. The extreme of this tendency is to be seen in *Sparganium* which has exactly reversed the long axis of the palisade cells. By this means the chloroplasts are placed in the most favorable position to utilize the weak light. It has been suggested that the impulse to the change in shape of the cells and the consequent thinning of the leaf comes from the mobility of the chloroplasts. In the majority of the shade-leaves the stretching of the palisade cells is more apparent at the top of the cell and the so-called " funnel " form is the result. This form of cell is well adapted to place the chloroplasts in a favorable position in respect to light and in consequence of the resulting spaces between, to allow the penetration of light to the interior of the leaf as well. The loose arrangement of the prolate palisade cells also serves this end, although probably also bound up with the necessity for an increase in transpiration.

LIGHT DECREASED; WATER AND HUMIDITY INCREASED

	Leaf	Cuticle	Palisade Amount	Palisade Kind	Palisade Texture
Galium triflorum	—	o	—	o	o
Thalictrum sparsiflorum	—	—	—	prolate to funnel	looser
Pseudocymopterus tenuifolius	—	o	—	o	looser
Gentiana acuta	—	—	— 1 row	less prolate	o
Chamaenerium angustifolium	—	—	—	prolate to funnel	looser
Aconitum columbianum	—	—	—	prolate to funnel	looser
Opulaster intermedia	—	—	—	prolate to funnel	looser
Viburnum pauciflorum	—	o	— 1 row	o	looser
Bursa bursa-pastoris (very large)	+	—	— 1 row	o	looser
Potentilla propinqua	o	—	o	o	looser
Prunus demissa	—	—	— ½ row	o	o
Blitum capitatum	—	o	— (1-2) rows	prolate to funnel	looser
Campanula petiolata	—	—	— 1 row	o	looser
Valeriana acutiloba	—	o	— (1-2) rows	prolate to funnel	o
Erigeron speciosus	o	o	o	o	o
Solidago extraria	—	—	—	o	o
Pseudocymopterus anisatus	—	—	—	o	looser
Gutierretzia sarothrae	—	—	— 2 rows	o	o
Euphorbia robusta	—	o	—	o	o
Senecio rosulatus	+	o	+	o	looser
Boebera papposa	—	—	— (3-4) rows	o	o
Aster torreyi	—	o	o	o	o
Machaeranthera aspera	—	—	— 3 rows	o	looser
Pachylophus caespitosus	—	o	— 5 rows	o	looser
Senecio spartioides	—	o	— 5 rows	o	looser
Allionia linearis	—	—	— 4 rows	o	o
Solanum triflorum	—	o	— 3 rows	o	looser
Helianthus pumilus	—	—	— (1-2) rows	o	looser
Thlaspi coloradense	—	—	—	o	looser
Vagnera stellata	—	—	o	o	looser
Geranium caespitosum	—	—	— 1 row	o	looser
Galium boreale (seedling)	—	—	— 1 row	prolate to funnel	looser
Holodiscus dumosa	—	—	— ½ row	more funnel	looser
Pentstemon glaucus	—	o	o	o	looser
Symphoricarpus oreophila	—	o	— 1 row	prolate to funnel	looser
Polygonum convolvulus	—	—	— 1 row	prolate to funnel	looser
Capnoides aureum	—	o	—	prolate to funnel	looser
Scutellaria brittonii	—	—	— (1-2) rows	o	looser
Therophon jamesii	—	—	— 1 row	prolate to funnel	looser
Atragene acutiloba	o	o	+	o	looser
Apocynum androsaemifolium	—	—	—	prolate to funnel	looser
Aralia nudicaulis	—	o	—	prolate to funnel	looser
Artemisia gnaphalodes	—	—	—	o	looser
Artemisia ludoviciana	—	—	—	prolate to funnel	looser
Monarda menthifolia	—	—	—	prolate to funnel	looser
Ximensia encelioides	—	o	— 1 row	o	o
Rudbeckia flava	+	—	— 1 row	o	looser

LIGHT DECREASED; WATER AND HUMIDITY INCREASED—*Continued*

	Leaf	Cuticle	Sponge Amount	Sponge Kind	Sponge Texture
Galium triflorum	—	o	—	more oblate	looser
Thalictrum sparsiflorum	—	—	—	more oblate	o
Pseudocymopterus tenuifolius	—	o	—	o	looser
Gentiana acuta	—	—	—	o	o
Chamaenerium angustifolium	—	—	—	globose to oblate	looser
Aconitum columbianum	—	—	—	irregular to oblate	looser
Opulaster intermedia	—	—	—	irregular to oblate	looser
Viburnum pauciflorum	—	o	+	o	looser
Bursa bursa-pastoris (very large)	+	—	+	more oblate	looser
Potentilla propinqua	o	—	o	more oblate	looser
Prunus demissa	—	—	—	more oblate	looser
Blitum capitatum	—	o	—	more oblate	looser
Campanula petiolata	—	—	—	more oblate	looser
Valeriana acutiloba	—	o	—	more oblate	looser
Erigeron speciosus	o	o	o	o	o
Solidago extraria	—	—	o	o	o
Pseudocymopterus anisatus	—	—	o	o	o
Gutierretzia sarothrae	—	—	o	o	o
Euphorbia robusta	—	o	o	o	o
Senecio rosulatus	+	o	o	o	o
Boebera papposa	—	—	—	prolate to globose	o
Aster torreyi	—	o	o	o	o
Machaeranthera aspera	—	—	—	prolate to oblate	looser
Pachylophus caespitosus	—	o	+	oblobate to irregular	looser
Senecio spartioides	—	o	+	oblobate to irregular	looser
Allionia linearis	—	—	o	oblobate to globose	o
Solanum triflorum	—	o	o	oblobate to subglobose	o
Helianthus pumilus	—	—	o	prolate to irregular	looser
Thlaspi coloradense	—	—	o	o	looser
Vagnera stellata	—	—	—	o	looser
Geranium caespitosum	—	—	—	more oblate	looser
Galium boreale (seedling)	—	—	—	more oblate	looser
Holodiscus dumosa	—	—	—	more oblate	looser
Pentstemon glaucus	—	o	—	o	looser
Symphoricarpus oreophila	—	o	+	more oblate	looser
Polygonum convolvulus	—	—	—	globose to oblate	looser
Capnoides aureum	—	o	—	oblong to oblate	looser
Scutellaria brittonii	—	—	—	subglobose to oblate	looser
Therophon jamesii	—	—	+	subglobose to oblate	looser
Atragene acutiloba	o	o	—	o	looser
Apocynum androsaemifolium	—	—	—	irregular to oblate	looser
Aralia nudicaulis	—	o	—	o	looser
Artemisia gnaphalodes	—	—	o	less prolate	looser
Artemisia ludoviciana	—	—	—	oblobate to oblate	looser
Monarda menthifolia	—	—	—	oblobate to oblate	looser
Ximensia encelioides	—	o	+	oblobate to subglobose	looser
Rudbeckia flava	+	—	+	prolate to star-shaped	looser

This group of polydemics is similar to the preceding one but with an increase in the available water. The effect of this is immediately seen in the looser arrangement and the increased oblateness of the sponge tissue. The increase in thickness indicated by some of the species must be viewed in the light of the fact that the shade-leaves are very much larger than the corresponding sun-leaves. This is especially striking in the case of *Bursa bursa-pastoris* which has an extremely large thin leaf in the shade and a very tiny thick one in the sun, and yet the absolute measurements show a thicker leaf in the shade. In the case of the diplophyll and staurophyll types, the sponge of the shade form has been evolved from the lower prolate and oblobate cells. Another point brought out by the above group is the relative stability of some species as compared with others. This is generally true of the composites, although they too show striking modifications in some cases.

LIGHT INCREASED; WATER UNCHANGED; HUMIDITY DECREASED

	Leaf	Cuticle	Palisade		
			Amount	Kind	Texture
Batrachium aquatile (dwarf)	—	o	+ 1 row	globose to prolate	o
Callitriche bifida (dwarf)	+	o	+	globose to prolate	o
Hippuris vulgaris (dwarf)	+	o	+	globose to prolate	o
Chenopodium fremontii	+	+	+	funnel to prolate	o
Heracleum lanatum	+	o	+	funnel to prolate	o
Acer glabrum	+	+	+	o	closer
Fragaria bracteata	+	o	+	funnel to prolate	o
Edwinia americana	+	+	+	o	closer
Thalictrum sparsiflorum	+	o	+	o	o
Senecio pudicus	+	+	+	prolate to oblobate	closer
Polemonium pulchellum	+	+	+ 1 row	funnel to prolate	closer
Pseudocymopterus tenuifolius	+	+	+	o	o
Chamaenerium angustifolium	—	o	—	o	o
Mertensia polyphylla	o	+	+	o	closer

LIGHT INCREASED; WATER UNCHANGED; HUMIDITY DECREASED—*Continued*

	Leaf	Cuticle	Sponge		
			Amount	Kind	Texture
Batrachium aquatile (dwarf)	—	o	—	o	closer
Callitriche bifida (dwarf)	+	o	+	o	closer
Hippuris vulgaris (dwarf)	+	o	—	globose to prolate	o
Chenopodium fremontii	+	+	+	oblate to globose	closer
Heracleum lanatum	+	o	+	o	o
Acer glabrum	+	+	+	oblate to prolate	closer
Fragaria bracteata	+	o	+	oblate to globose	closer
Edwinia americana	+	+	+	o	closer
Thalictrum sparsiflorum	+	o	o	less oblate	o
Senecio pudicus	+	+	+	o	o
Polemonium pulchellum	+	+	—	oblate to globose	closer
Pseudocymopterus tenuifolius	+	+	—	less oblate	o
Chamaenerium angustifolium	—	o	+	o	closer
Mertensia polyphylla	o	+	—	o	closer

Under the influence of increased light and the usual accompanying reduction in humidity and available water, changes in leaf structure opposite to those in the preceding group are to be expected and do obtain. The leaf is increased in thickness, involving, as a rule, increase in both palisade and sponge tissues. In the case of *Batrachium aquatile,* the plant is dwarfed and the measured decrease is not relative to leaf surface. The leaf of *Chamaenerium* is but a trifle thinner than for the type, although the light is slightly greater. The cuticle is thickened as a rule, and the tendency of both palisade and sponge cells is to extend vertically at the expense of the horizontal axis. This form of cell is best adapted for screening the chlorophyll from over-illumination, and for most active assimilation. In respect to arrangement of cells, there is a marked reduction in intercellular spaces, thus decreasing transpiration and interior illumination. The extreme adaptations for the group are in the spongophyll type of aquatic leaves which have changed from well aerated sponge tissue to characteristic prolate palisade cells with few intercellular spaces. The dwarfing of these three species may be referred to the great reduction in available water: in the aquatic plant, absorption takes place by means of the entire plant, whereas the amphibious form has but few tiny rootlets.

LIGHT, WATER AND HUMIDITY INCREASED

	Leaf	Cuticle	Palisade			Sponge		
			Amount	Kind	Texture	Amount	Kind	Texture
Geranium richardsonii	+	+	+ 1 row	prolate to oblobate	o	+	less oblate	o
Primula parryi	+	o	+ 1 row	o	o	—	o	looser
Chamaenerium angustifolium	—	o	—	prolate to oblobate	looser	o	o	looser

The only additional point brought out by this small group of plants is the transformation of prolate palisade cells into oblobate cells. These doubtless serve two purposes, that of palisade proper in response to the strong illumination, and that of sponge since the lobes furnish an increase of transpiring surface called forth by the abundant water supply. *Chamaenerium* has been slightly dwarfed by the excess of the latter.

VII. Summary

The spongophyll type of leaf is characteristic of extreme hydrophytic situations. It is a practically homogeneous structure of simple globose cells enclosing air-passages, and is in accord with the surrounding medium of water and diffuse light. The spongophyll is also characteristic of monocotyledons where it is hereditary rather than adaptational. At the other extreme as regards both physical conditions and leaf structure is found the staurophyll as characteristic of intense xerophytes. It is composed entirely of prolate cells usually to the exclusion of any considerable amount of air space, or it is combined with more frequent intercellular spaces and water-storage cells. The diplophyll is closely connected with the staurophyll and the two comprise the type of leaf called "isolateral" by Heinricher and studied by him in connection with the vertical position of leaves. He has ascribed to light by far the greater influence in producing this structure, and has given to dryness a very subordinate value. It is true that light is the important factor, but for the extreme development of the type, lack of moisture must play an active part. This is evident when it is remembered that besides being the form best adapted to great assimilative activity and to the prevention of over-illumination, the prolate form of cell per-

mits the fewest intercellular spaces and hence reduces harmful transpiration where the water-supply is limited. Moreover, as noted by Heinricher and brought out in this paper, the isophotic structure of leaves is incompletely present in those which grow in wet sunny habitats. In such cases the ancestral type is being modified by wetter conditions. Heinricher has also observed that the vertical leaves of sunny swamp plants and water plants are not completely isolateral. This indicates that dryness is a necessary factor. The layer of palisade on the under side of these leaves has been explained as due to reflected light in the case of horizontal leaves and to either incident or reflected light for those vertically placed. It is worthy of note that the species covered in this paper, which have isophotic leaves, whether of the staurophyll or diplophyll type, are not generally vertical. As a rule, however, the diplophyll with internal sponge, such as is characteristic of the *Agoseris* group, is typical of vertical leaves in moist situations, while the diplophyll with interior water-storage tissue (*Solidago, Mertensia,* etc.), and the staurophyll, whether with (*Helianthus*) or without (*Pentstemon*) water-storage cells, include both vertical and horizontal leaves and are characteristic of habitats with high light values and dryness of soil, connected as a rule with reflected light and heat.

Between the two extremes of physical factors and of leaf structure lie the sun and shade mesophytes which furnish examples of all intergrades. A typical mesophyll unites equal percentages of palisade and of sponge tissues with moderate looseness in the cell-arrangement. The amount and combinations of the physical factors for any mesophyte can be very nearly approximated by a study of the amount and character of the chlorenchym cells.

Experiments with respect to sun-leaves and shade-leaves have been numerous. Dufour's have led to the conclusions that sun-leaves are larger and better developed in every way than shade-leaves, and that the size of shade-leaves as generally observed is due to water-content. His results are not convincing, since his light and shade experiments were made with typical sun-plants. These under normal conditions would doubtless thrive and show better development in every way than when grown under abnormal light conditions. Also, in proving that it is water and not shade which causes development in leaf surface, he has used extremes of water-content, ignoring the fact that extreme conditions dwarf

plants, and extreme dryness more so than extreme moisture. It is evident from the present paper that increase of both shade and water-content within certain limits which differ for the species, tend to increase the surface extent of leaves and to decrease thickness, and that shade is more efficient in this respect than water.

Stahl's general results concerning sun-leaves and shade-leaves are confirmed in this paper, although exception is here taken to his suggestion that the impulse to surface growth in leaves comes from the veins. These are relatively inflexible and insensible to the influence of light. It is more than likely that the impulse comes from that part of the leaf which is sensitive to light changes, *e. g.*, the chloroplasts.

It has not been found that the alpine forms of species show as uniform differences as is evident from Bonnier's experiments. Further investigation with more exact records of factors will be necessary before satisfactory conclusions can be reached along this line.

The theory of the most direct transport of food materials, as formulated by Haberlandt and confirmed by Heinricher, does not seem sufficient to explain all the facts of leaf structure. It is even admitted by these investigators to fail in some notable instances. In connection with this theory of transport, it would seem that the theory of support would have some part, perhaps the greater, in curving the cells towards the bundles, in as much as there is no satisfactory evidence of a current of diffusion.

It is clear from all that has been done in the past that an intelligent study of leaf structure must be made in the future upon the following basis: (1) the hereditary structure, which should include considerations of size, shape and position of leaf, as well as histology and modifications such as hairs, stomata, mucilage cells and the like; (2) exact records of the physical factors of the habitat of the species for the day and for the growing season; (3) the physiological processes of the leaf: (4) the interrelation and correlation of the preceding data.

The present investigations fall short in as much as they have considered only internal leaf structure, and contain somewhat incomplete records of physical factors. It is hoped, however, that the results obtained may not be without value. They are as follows:

1. A typical hydrophyll consists entirely of sponge cells and air-spaces.

2. A typical xerophyll consists entirely of palisade cells with few air-spaces and with or without water-storage tissue.

3. A typical mesophyll consists of equal amounts of palisade and sponge tissue, and moderate air-spaces.

4. Decreased light and increased water both cause an increase in leaf surface and a decrease in thickness.

5. The lateral tension in the cells which causes a thinning of the leaf is due to the sensitiveness of chlorophyll to light.

6. In weak light the chloroplasts arrange themselves in the most favorable position for the absorption of the light.

7. The tension in the cell caused by the lateral arrangement of the chloroplasts increases the horizontal axis of the cell at the expense of the vertical axis and gives rise to funnel, globose and oblate cells.

8. Decreased light causes a somewhat looser arrangement of the chlorenchym cells, and especially of the palisade.

9. Increased water causes an increase in the transpiring surface of the cells, hence looser arrangement, especially of the sponge cells, and oblobateness of prolate cells.

10. A woolly covering of hairs decreases the light and transpiration for the chlorenchym tissues and hence permits looser arrangement of the cells.

11. Increased light and decreased water both cause a reduction in leaf surface and increase in thickness.

12. In strong light the chloroplasts arrange themselves vertically in order to screen against over-illumination.

13. The vertical tension in the cell caused by the vertical position of the chloroplasts increases the vertical axis of the cells at the expense of the horizontal axis, and gives rise to prolate and prolobate cells.

14. Strong light causes a closer arrangement of the chlorenchym cells, and especially of the palisade.

15. Decreased water causes a decrease in transpiring surface and hence closer arrangement of the cells, especially of the sponge, and prolateness in the sponge cells.

16. Humidity is closely connected with water-content, but is also directly efficient in changing the cuticle.

17. Temperature acts indirectly upon the plant through water and humidity.

18. Altitude affects plants through low humidities and shortness of season.

19. Extremes of any factor which are not the optimum for the species tend to dwarf plants growing in them.

20. Species are plastic in different degrees. The greatest stability is shown by the composites, although stable species occur among other families.

21. No laws can as yet be laid down as to the exact amount of change taking place in the histology of the leaf in response to a definite difference in the physical factors. Among plastic species it is proportional within certain limits, but beyond these epidermal and morphological modifications must be taken into account.

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PLATE I

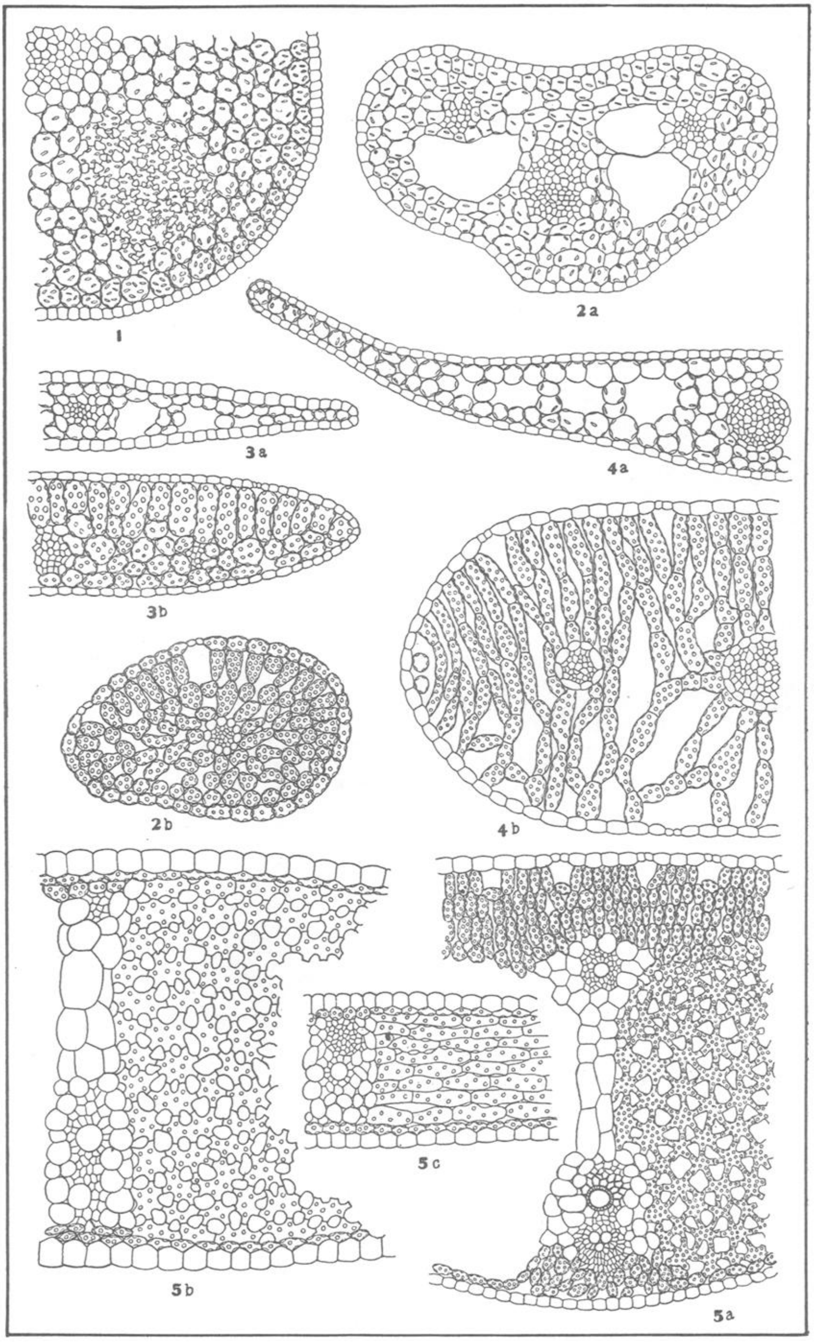


PLATE II

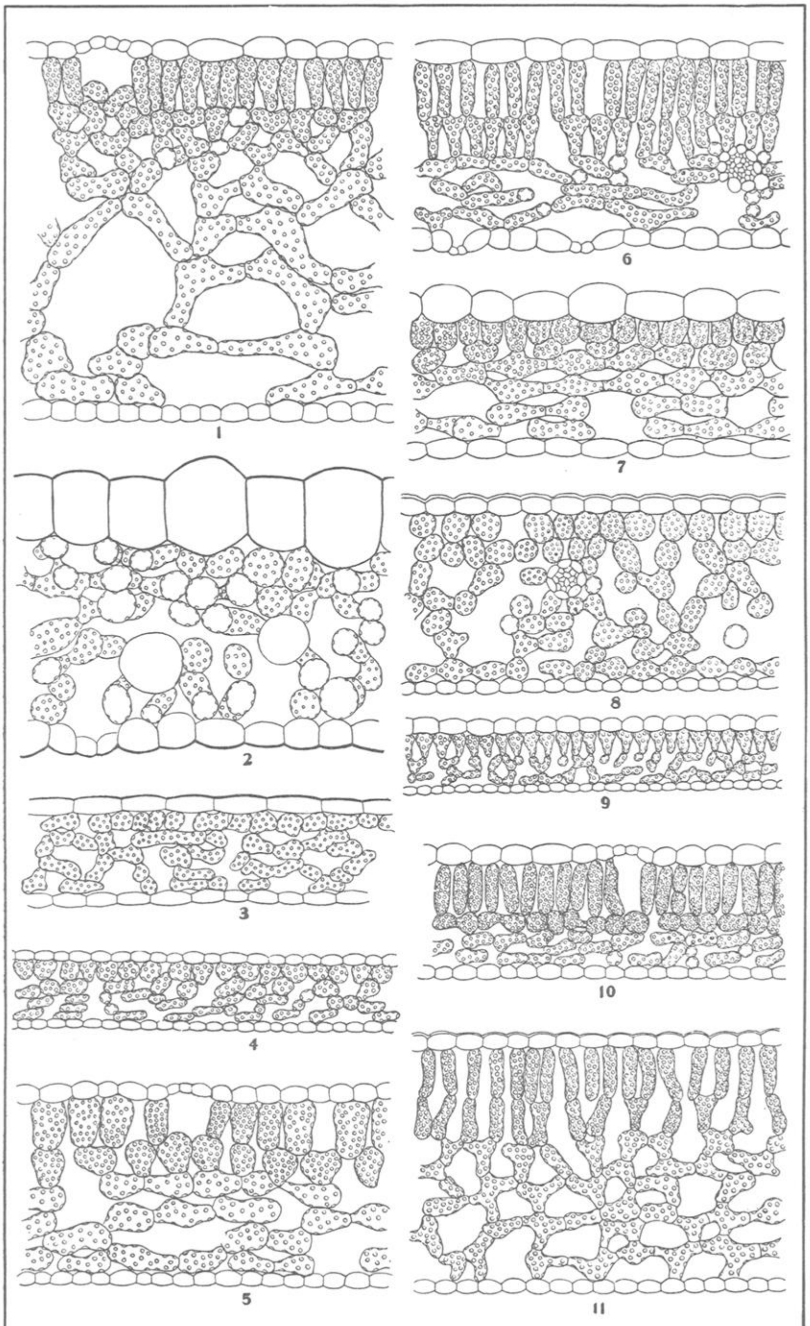
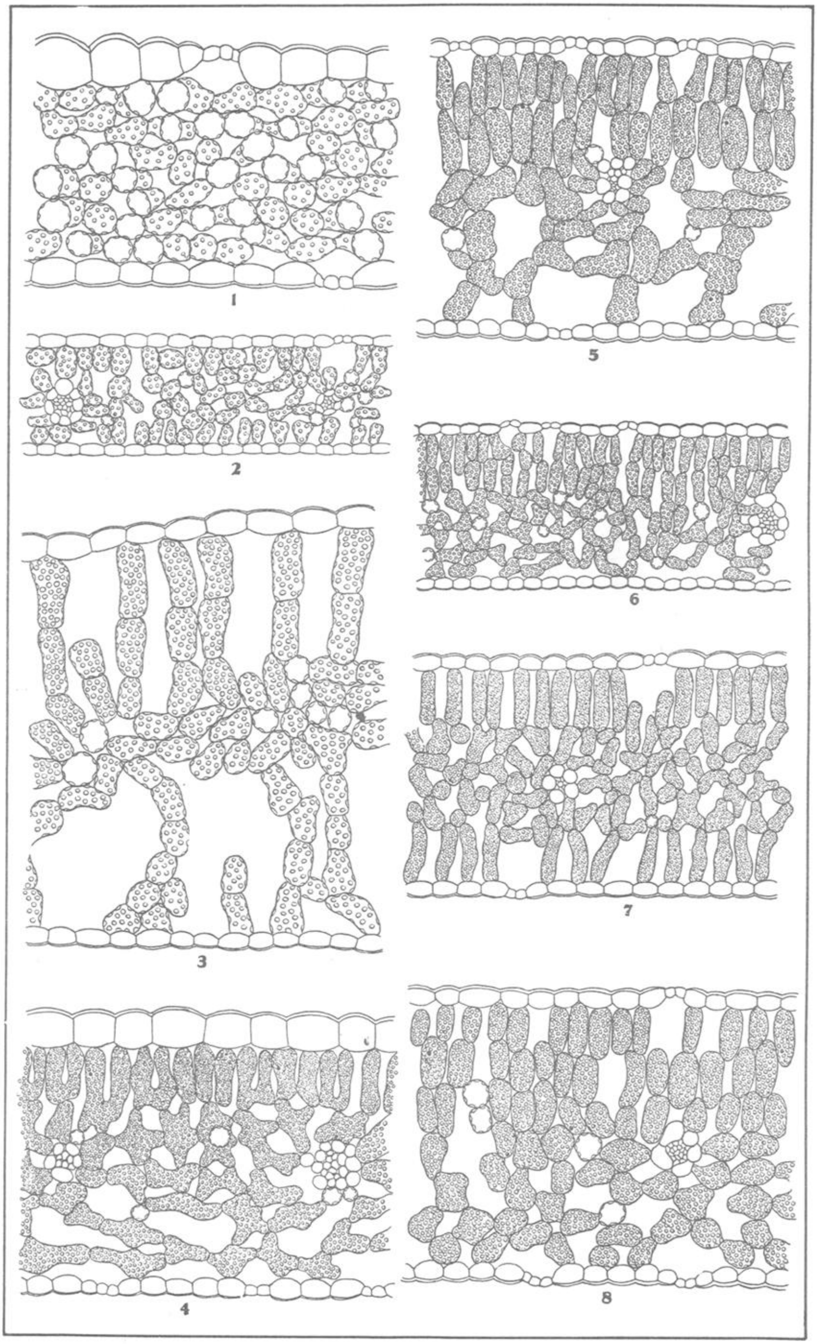


PLATE III



IX. EXPLANATION OF PLATES

All the figures are of cross-sections of the leaf, drawn to a scale of 100 magnifications.

Plate I

Fig. 1. *Isoetes lacustris paupercula,* alpine lake.
Fig. 2. *Batrachium aquatile,* alpine lake.
 a. Submerged.
 b. Amphibious.
Fig. 3. *Callitriche bifida,* alpine lake.
 a. Submerged.
 b. Amphibious.
Fig. 4. *Hippuris vulgaris,* alpine lake.
 a. Submerged.
 b. Aerial.
Fig. 5. *Sparganium angustifolium,* alpine lake.
 a. Floating.
 b. Submerged.
 c. Deeply submerged.

Plate II

Fig. 1. *Saxifraga punctata,* shady brook bank.
Fig. 2. *Limnorchis stricta,* shady brook bank.
Fig. 3. *Vagnera leptosepala,* shady brook bank.
Fig. 4. *Epilobium adenocaulon,* shady brook bank.
Fig. 5. *Saxifraga debilis,* alpine rock cleft.
Fig. 6. *Cicuta grayii,* alpine rock cleft.
Fig. 7. *Adoxa moschatellina,* alpine spruce forest.
Fig. 8. *Moneses uniflora,* subalpine spruce forest.
Fig. 9. *Parietaria pennsilvanica,* subalpine spruce forest.
Fig. 10. *Viola palustris,* subalpine spruce forest.
Fig. 11. *Arnica cordifolia,* subalpine spruce forest.

Plate III

Fig. 1. *Gyrostachys stricta,* open spruce forest.
Fig. 2. *Castilleia sulphurea,* open spruce forest.
Fig. 3. *Clementsia rhodantha,* sunny bog.
Fig. 4. *Lilium montanum,* sunny brook bank.
Fig. 5. *Senecio crocatus,* sunny bog.
Fig. 6. *Veronica wormsjoldii,* alpine meadow.
Fig. 7. *Agoseris aurantiaca,* alpine meadow.
Fig. 8. *Draba streptocarpa,* alpine meadow.

Plate IV

Fig. 1. *Salix saximontana,* alpine meadow.
Fig. 2. *Populus tremuloides,* aspen forest.
Fig. 3. *Antennaria* sp., aspen clearing.
Fig. 4. *Phacelia lyallii,* alpine meadow.
Fig. 5. *Pedicularis procera,* aspen forest.
Fig. 6. *Heuchera parvifolia,* alpine meadow.
Fig. 7. *Pseudocymopterus montanus purpureus,* alpine meadow.
Fig. 8. *Gentiana affinis,* foothills.
Fig. 9. *Touterea multiflora,* subalpine gravel.
Fig. 10. *Mertensia linearis,* foothills.

Plate V

Fig. 1. *Solidago pallida,* foothills.
Fig. 2. *Asclepiodora decumbens,* foothills.
Fig. 3. *Grindelia squarrosa,* foothills.
Fig. 4. *Helianthus scaberrimus,* foothills.
Fig. 5. *Astragalus drummondii,* foothills.
Fig. 6. *Arabis fendleri,* half gravel.
Fig. 7. *Pentstemon unilateralis,* foothills.
Fig. 8. *Bahia dissecta,* foothills.

Plate VI

Fig. 1. *Acer glabrum.*
a. Subalpine spruce forest.
b. Subalpine thicket.
c. Half gravel.
Fig. 2. *Galium triflorum.*
a. Subalpine spruce forest.
b. Shady brook bank.
Fig. 3. *Geranium richardsonii.*
a. Subalpine spruce forest.
b. Sunny brook bank.
Fig. 4. *Polemonium pulchellum.*
a. Alpine spruce forest.
b. Alpine gravel.
Fig. 5. *Chamaenerium angustifolium.*
a. Aspen forest.
b. Alpine rock cleft.
c. Subalpine thicket.
d. Alpine thicket.
Fig. 6. *Rudbeckia laciniata.*
a. Shady brook bank.
b. Aspen clearing.

PLATE IV

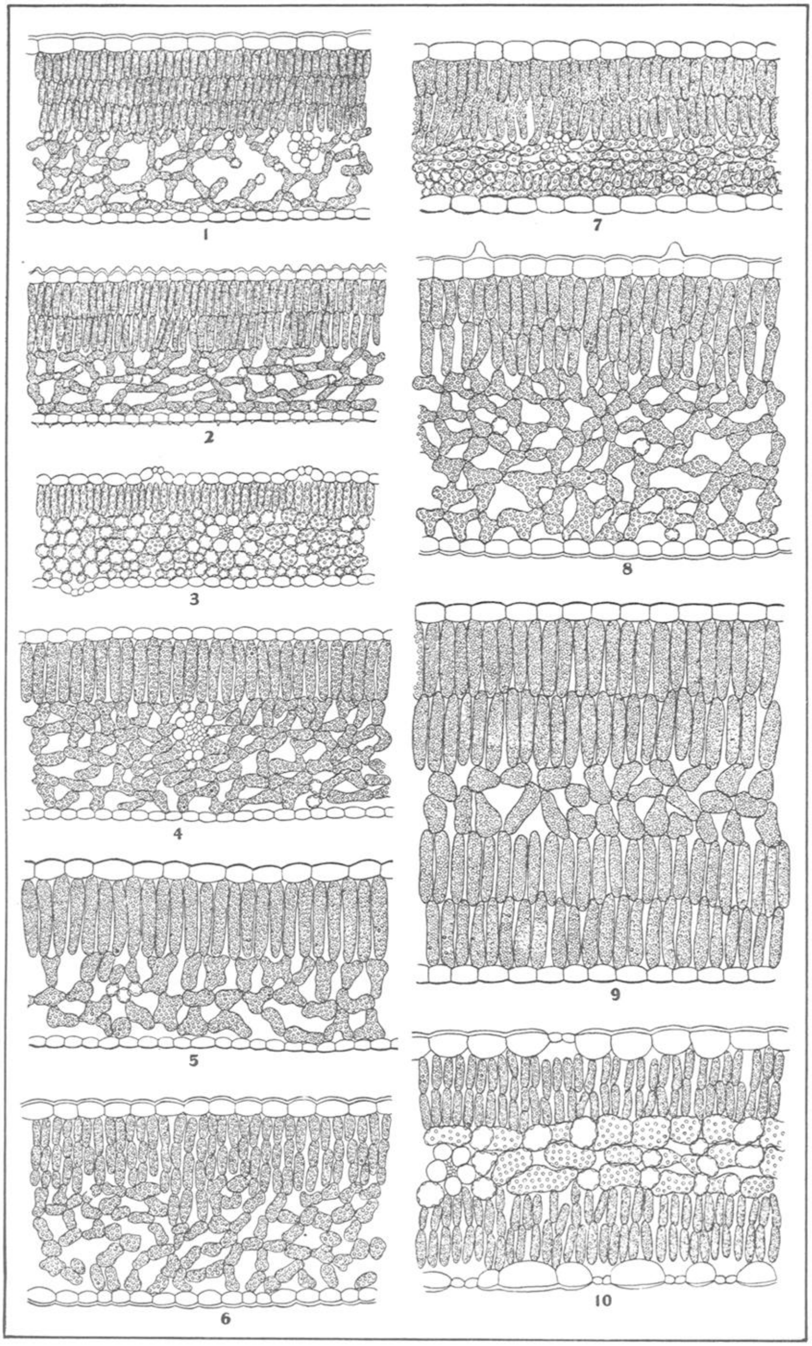


PLATE V

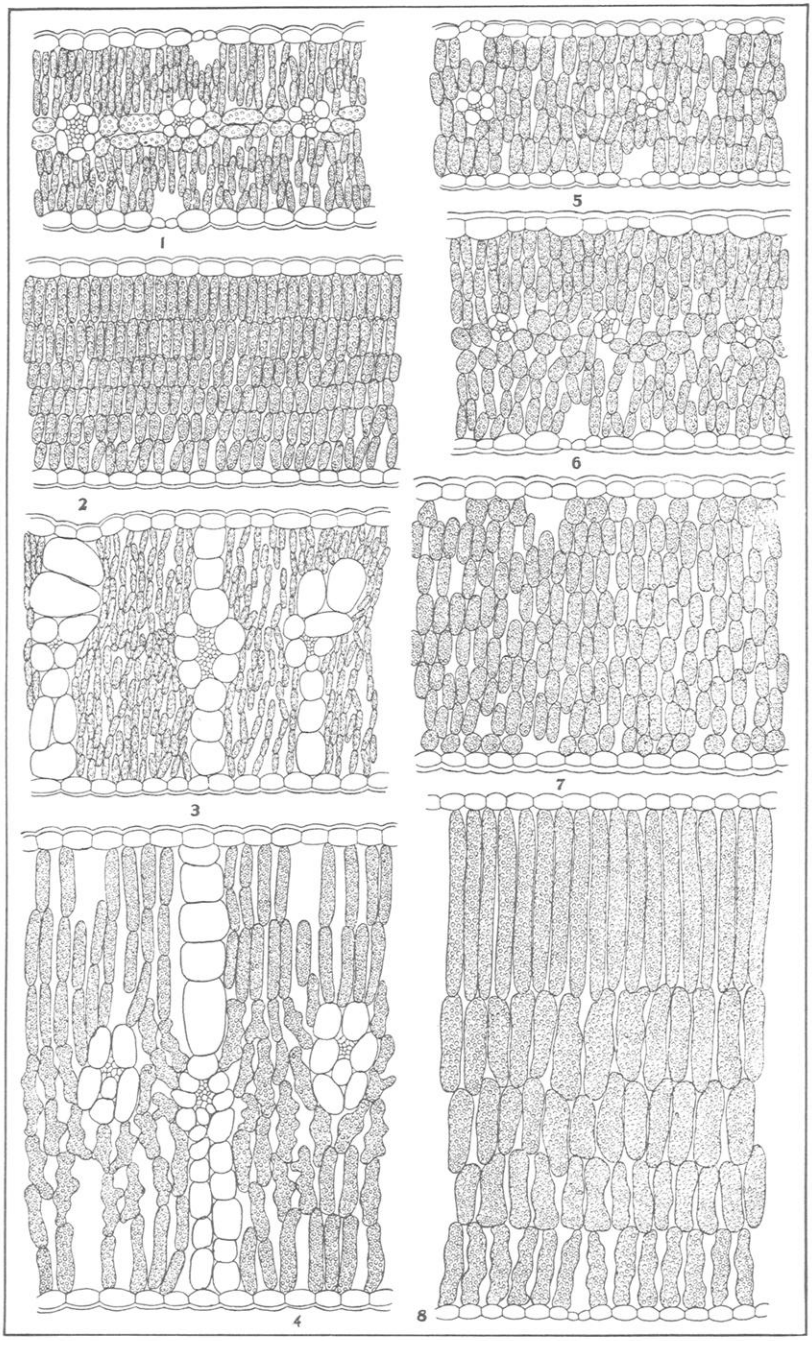


PLATE VI

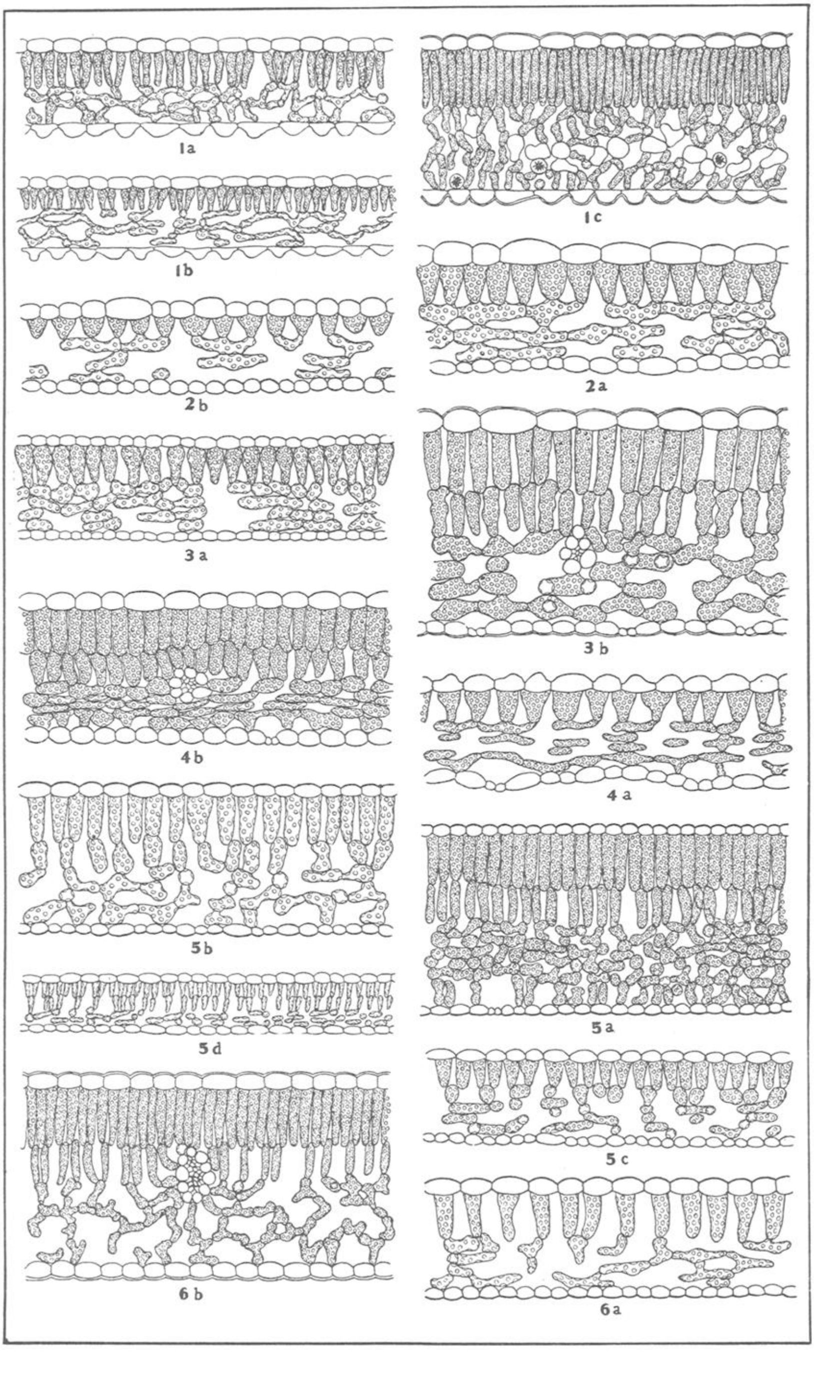


PLATE VII

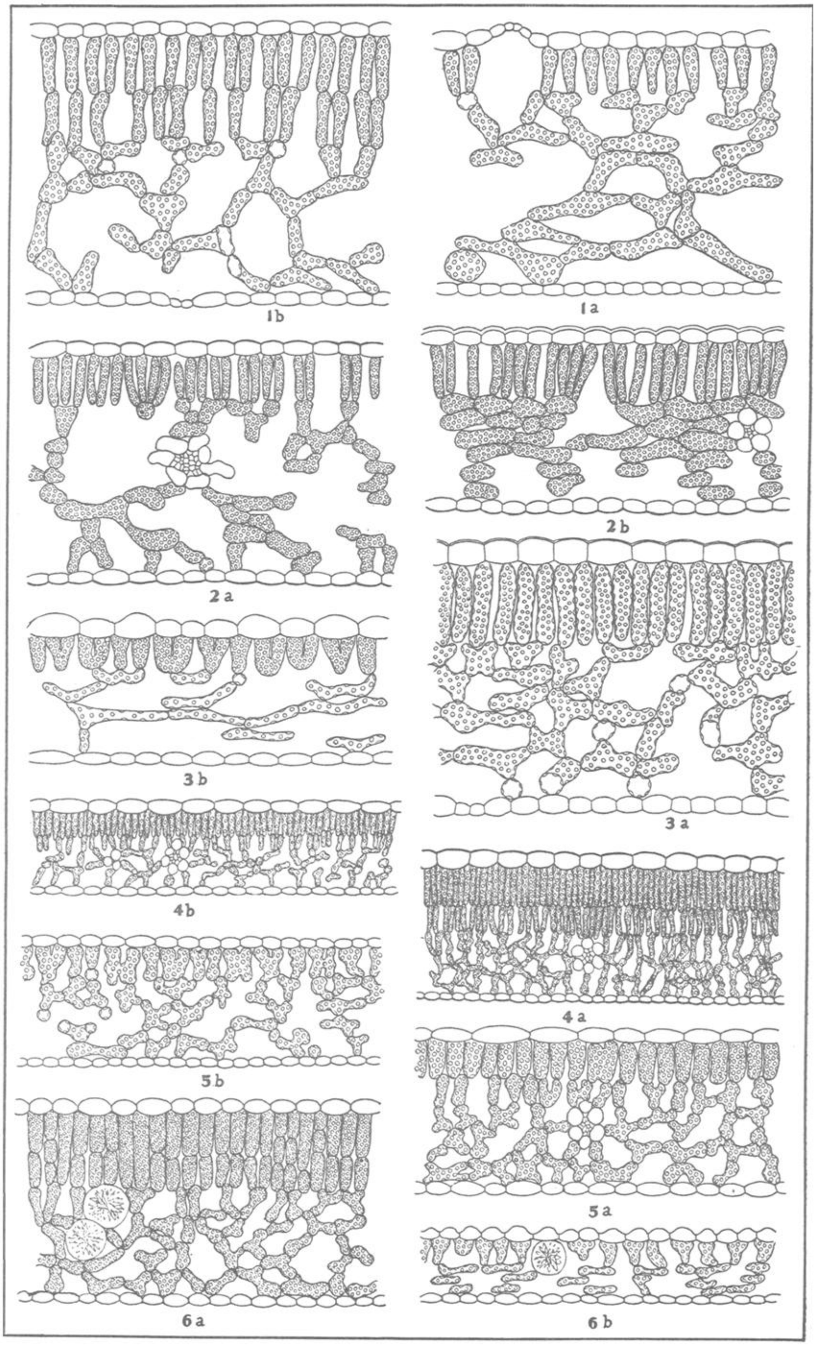


PLATE VIII

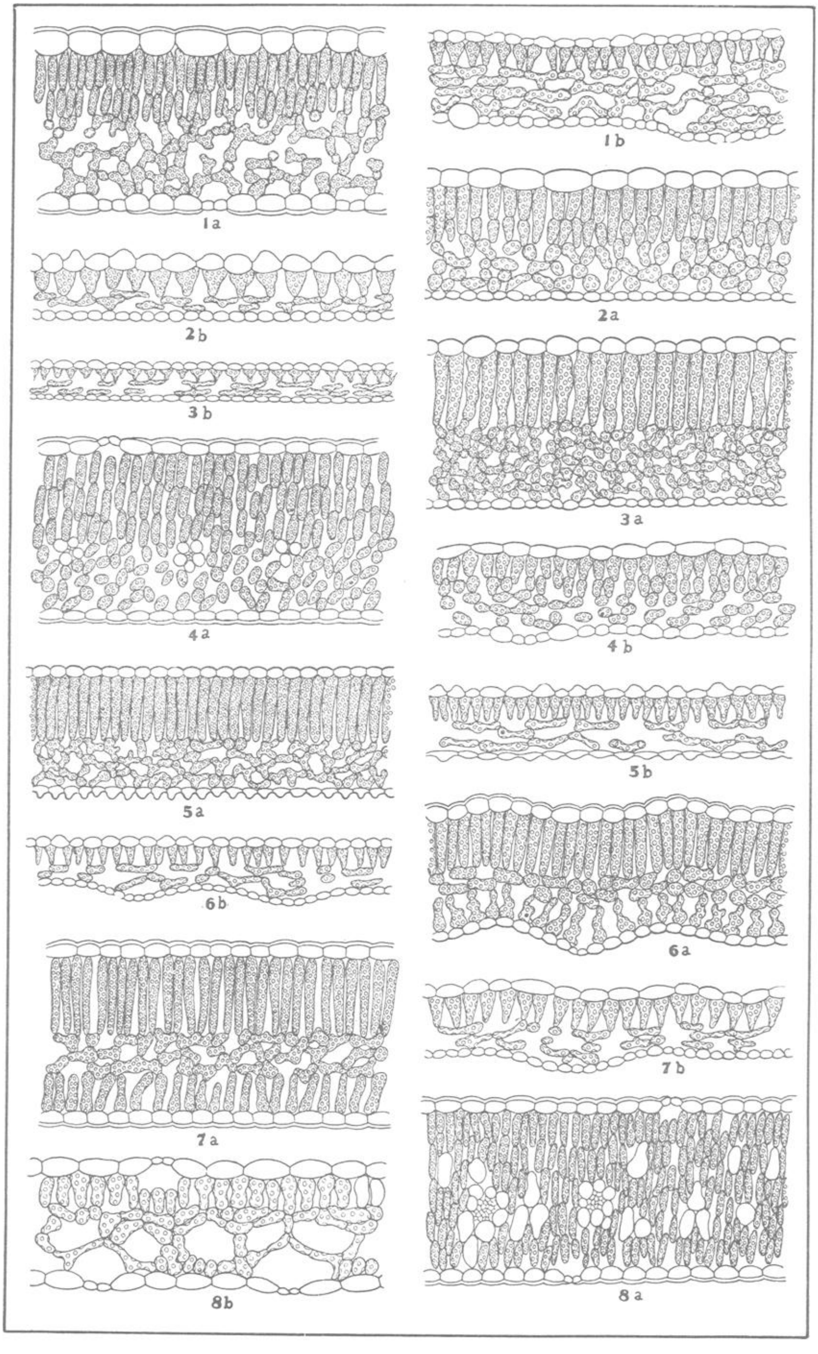


Plate VII

Fig. 1. *Primula parryi.*
a. Alpine rock cleft.
b. Sunny brook bank.
Fig. 2. *Mertensia polyphylla.*
a. Sunny brook bank.
b. Alpine meadow.
Fig. 3. *Aconitum columbianum.*
a. Sunny brook bank.
b. Shady brook bank.
Fig. 4. *Quercus novimexicana,* gravelly brook bank.
a. Sun-leaf.
b. Shade-leaf.
Fig. 5. *Viburnum pauciflorum.*
a. Sunny brook bank.
b. Thicket.
Fig. 6. *Blitum capitatum.*
a. Half gravel.
b. Subalpine thicket.

Plate VIII

Fig. 1. *Galium boreale.*
a. Subalpine gravel.
b. Subalpine spruce forest.
Fig. 2. *Polygonum convolvulus.*
a. Foothill gravel.
b. Shady brook bank.
Fig. 3. *Bidens bigelovii.*
a. Foothill half gravel.
b. Foothill thicket.
Fig. 4. *Scutellaria brittonii.*
a. Subalpine gravel.
b. Subalpine thicket.
Fig. 5. *Apocynum androsaemifolium.*
a. Subalpine gravel.
b. Subalpine thicket.
Fig. 6. *Artemisia ludoviciana.*
a. Foothill mesa.
b. Foothill thicket.
Fig. 7. *Monarda menthifolia.*
a. Subalpine half gravel.
b. Subalpine thicket.
Fig. 8. *Machaeranthera aspera.*
a. Subalpine gravel.
b. Shady brook bank.

Plate IX

Fig. 1. *Pachylophus caespitosus.*
a. Foothill gravel.
b. Foothill thicket.
Fig. 2. *Allionia linearis.*
a. Subalpine gravel.
b. Foothill thicket (tall).
c. Foothill thicket (seedling).
Fig. 3. *Solanum triflorum.*
a. Subalpine half gravel.
b. Foothill thicket.
Fig. 4. *Helianthus pumilus.*
a. Foothill half gravel.
b. Foothill thicket.

PLATE IX